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ON STANDARDS OF WAVE-LENGTHS.

By H. KAYSER.

WHEN Rowland published his table of standards, the forward step appeared so great, the accuracy and the instrumental means of so high an order, that we seemed to have in hand the foundation for all measurements for many years, perhaps forever. But this hope was shaken when Michelson determined the wave-lengths of three *Cd* lines. That the absolute values differed from Rowland's by 0.2 tenth-meter was of little importance, and could astonish nobody having read critically the determinations made with the grating by Müller and Kempf, Kurlbaum, and Bell, as they clearly show the impossibility of attaining with the grating an accuracy exceeding 0.1 tenth-meter; but the relative differences were unexpected:

Michelson	λ 6438.472	5085.824	4799.911
Rowland	6438.680	5086.001	4800.097
Difference	0.208	0.177	0.186

These differences are not proportional to the wave-lengths. If the second line is relatively correct, the two other differences should be 0.222 and 0.166; *i. e.*, the first line of Rowland is by 0.014 too low, the third line by 0.020 too high, while according to Rowland we should expect to find no errors exceeding 0.005 tenth-meter.

It seemed possible, however, that only a few lines from Rowland's table had a larger error, and that unfortunately the *Cd* lines were of this kind, but that nevertheless the relative accuracy for the whole spectrum was that given by Rowland.

Now came the absolute determinations by Perot and Fabry of a great number of iron and Fraunhofer lines, made by the much more accurate interference method, and based upon Michelson's *Cd* lines. They show that Rowland's measurements are not nearly so correct, relatively, as we had supposed, and that his system is not sufficient for our needs. With a correct system of standards we could now determine the wave-lengths of all the sharp lines—and 99 per cent. of all the lines can be got sharp—with an accuracy of a few thousandths of an Ångström unit. I am sure that the much larger differences found by different observers are caused very often by the use of different, relatively incorrect, standards.

From extensive use of Rowland's tables I had long ago found that his system is less correct than was generally supposed, and I had tried to amend it. I think that my standards from the iron arc are better, but of course they have the same general feature as Rowland's standards, as will be evident by my method of working, so that alternating parts with positive and negative errors must be common to both systems.

It seems urgent, therefore, to get better standards, as most of the measurements made up to this time with Rowland's standards will prove useless as far as the wave-length is concerned. But before beginning with such a task we must know what were the errors committed by Rowland, that we may avoid them, and we must carefully consider the easiest and most exact way to get better results.

It is quite clear that Rowland's *measurements* have not been erroneous, as his plates, his measuring machine, and his and Mr. Jewell's ability were first-rate. The method of *using* the measurements, therefore, must have been erroneous. I think there are two causes for the bad results: Rowland did not know the difference between the position of solar and arc lines. Even the first step, taking the solar D lines for the arc spectra, was

doubtful. We do not know exactly how Rowland's computations were made, but Mr. Jewell says:

> As Professor Rowland was not convinced that the displacement was due to any other cause than the accidental movement of the apparatus, when changing from the spectrum of the Sun to that of the arc, the displacement was treated as due to this cause, and the wave-lengths of all metallic lines corrected for the average displacement of the stronger "impurity lines" (generally iron) upon the plate, thus reducing them to an approximate agreement with the corresponding solar lines.[1]

Rowland has thus shifted different parts of the spectrum to smaller or greater wave-lengths, and as from such parts by the method of coincidences other parts have been determined, perhaps with another shifting, it is impossible to know to what extent the errors may have accumulated in different parts.

If this were the only cause of error, it would be easy to avoid it. We should then again apply the method of coincidences, but using exclusively arc lines and using as basis one, or better all, of the lines determined by Fabry and Perot. It is true that we cannot be quite sure of the correctness of these measurements. After reading all the papers of Perot and Fabry, I am personally inclined to believe their numbers exact; but as this can be rendered certain only by new measurements, Dr. Eversheim has undertaken this task in my laboratory by using Perot and Fabry's method and apparatus.

But there may be yet another cause for the inaccuracy of Rowland's results. As it is impossible to get exact absolute measurements with the grating, the method of coincidences also may have led to errors. Indeed, Michelson has lately shown that an error in the ruling of gratings is possible which falsifies the results of this method, and there may be other causes not yet found with the same effect.

Therefore the applicability of the method of coincidences with Rowland's grating must first be tried. It seems possible to test at the same time the exactness of Perot and Fabry's numbers. If we go by the method from one line of Perot and Fabry to another of their lines, and if we so find exactly their numbers, it seems very improbable that both this method and their num-

[1] ASTROPHYSICAL JOURNAL, 3, 89–113, 1896.

bers are false, and that the two errors have exactly compensated one another; we should rather conclude that method and numbers are right. If, on the other hand, we find other numbers than those of Perot and Fabry, either these numbers, or the method, or both, may be erroneous.

I have two of Rowland's largest concave gratings of 21 feet radius and 5.5 inches breadth, the first ruled on Rowland's third engine with 16,000 lines to the inch, the second ruled on the second engine with 20,000 lines to the inch. With the first grating Dr. Konen prepared for me plates containing Perot and Fabry's lines at λ 5302 and 5434, in the second order, coinciding with λ 3550 to 3630 in the third order. The wave-lengths of the lines in the third order were determined from Perot and Fabry's lines. Then other plates were procured containing these lines in the fourth order; on them appear at the same time Perot and Fabry's lines at λ 4736 and 4859 in the third order, so that their wave-length could be determined. I found in this manner, for instance, 4736.804, instead of Perot and Fabry's number, 4736.785. As the different measurements on different plates agree for the same line to 0.003 Å, it is obvious that either the grating is not to be used for the method of coincidences, or Perot and Fabry's numbers are not correct.

I then used the second grating. The line of Fabry and Perot λ 4859 in the second order gives the wave-lengths near λ 3240 in the third order. If λ 3240 is then photographed in the second order, we get Fabry and Perot's lines 6495 in the first order. I obtained in this manner in the first position the wave-lengths:

			Mean
3230.922	.923	.920	.922
3233.008	.009	.005	.007
3236.180	.178	.179	.179
3239.392	.394	.390	.392
3244.160	.160	.159	.160
3245.942	.940	.935	.939
3246.921	.919	.919	.920
3248.162	.160	.158	.160

Determining from these lines on the second plate the line 6495, I got 6494.884, whereas Perot and Fabry have 6494.992.

The difference, 0.108 Å, is much greater than for the first grating, but the conclusion to be drawn is the same.

I finally compared the two gratings directly. With each grating two plates of the region λ5302 to λ5434 in the second order were procured and the lines of the third order determined. I thus obtained the following numbers:

Grating with 20,000 Lines			Grating with 16,000 Lines			Difference
First Plate	Second Plate	Mean	First Plate	Second Plate	Mean	
3541.068	.069	.069	.103	.101	.102	0.033
3553.716	.719	.718	.756	.751	.754	0.036
3558.494	.493	.494	.532	.531	.532	0.038
3565.356	.361	.359	.396	.393	.395	0.036
3570.078	.082	.080	.117	.113	.115	0.035
3586.966	.965	.966	.003	.002	.003	0.037
3606.667	.663	.665	.697	.696	.697	0.032
3608.845	.841	.843	.879	.876	.878	0.035
3617.782	.778	.780	.805	.809	.807	0.027
3621.452	.447	.450	.478	.477	.478	0.028
3621.996	.991	.994	.019	.019	.019	0.026

By the difference of nearly 0.03 Å, it is evident that the two gratings give different results, and that they both are not to be used for the coincidence method. The slow decrease in the differences is occasioned by a weak line of the third order coinciding so nearly with the line 5302 on the plates from the first grating that it falsified this measurement, while on the plates from the second grating the lines were separated enough.

It seems, therefore, that we have no reason to doubt the accuracy of Perot and Fabry's values, but that the method of coincidences is not applicable for my gratings. Perhaps there may exist gratings free from this fault, but every one must be carefully tested before using.

I have then no means for procuring a better system of standards, as I had hoped to do by application of the method of coincidences on all the lines measured by Perot and Fabry. The only possibility of getting such standards seems to lie in the absolute determination by the interference method of one or two dozen more lines in the ultra-violet, between which other lines could then be interpolated from concave grating photographs.

Bonn, February 1904.

SPECTRA FROM THE WEHNELT INTERRUPTER. I.

By Harry W. Morse.

Nearly everyone who has written on the subject of the electrolytic interrupter of Wehnelt has noticed and described the brilliant light which is produced about the "active" electrode when the interrupter is in action. Wehnelt himself[1] examined this light and states that he found in its spectrum lines of hydrogen, the D lines of sodium, and when the active electrode was made negative, many other bright lines. Voller and Walter[2] made a more complete qualitative study of the spectra and found that apparently any metal, when used as active electrode in the Wehnelt arrangement, gave its characteristic spectrum. They speak also of the fact that it was frequently necessary to change the electrolyte, as the metal which had been used in preceding experiments as active electrode contaminated succeeding spectra and showed its own lines together with those of the metal under examination. These same facts have been brought out more fully, though still in a very crude and qualitative way, by Hoppe[3] and Werner von Bolton,[4] both of the latter suggesting the use of the phenomenon for producing colored light and spectra for demonstration. Simon[5] states that in the form of interrupter which he used, in which the break takes place, not at a metal point, but in the electrolyte at a narrow opening in a dividing diaphragm between two large electrodes, the same light-phenomena are produced, but no further data on the spectra are given. Hale[6] examined the spectrum of an iron point in the Wehnelt interrupter in connection with other spectra produced by the arc under liquids. Konen[7] in a paper on the same sub-

[1] *Wied. Ann.*, **68**, 233, 1899.

[2] *Wied. Ann.*, **68**, 539, 1899.

[3] *Electrotech. Ztsch.*, **21**, 507, 1900.

[4] *Ztsch. f. Electrochem.*, **9**, 913, November 1903.

[5] *Wied. Ann.*, **68**, 860, 1899.

[6] Astrophysical Journal, **15**, 131, 1902.

[7] *Ann. der Phys.*, **9**, 742, 1902.

ject also speaks of these spectra, but appears to consider the light too feeble to permit of photography of the spectrum.

The present paper contains the first part of a research on the spectra produced by an arrangement similar to the Wehnelt interrupter, with tables of the wave-length and approximate intensities of lines of the following metals, together with comparison tables and plates of lines produced in the arc and condensed spark:

Lithium — Carbon point in solution of lithium chloride.
Sodium — Carbon point in solution of sodium chloride.
Potassium — Carbon point in solution of potassium chloride.
Magnesium — Wire in hydrochloric acid.
Calcium — Platinum point in solution of calcium chloride.
Strontium — Platinum point in solution of strontium chloride.
Barium — Platinum point in solution of barium chloride.
Aluminium — Wire in hydrochloric acid.
Silver — Wire in hydrochloric acid.
Zinc — Wire in hydrochloric acid.
Mercury — Platinum point in solution of mercuric nitrate.
Tin — Wire in hydrochloric acid.
Lead — Wire in hydrochloric acid.

It is the intention to present in this paper the more general study of the phenomena, and those spectra have therefore been selected from the plates at hand which are simplest and show marked points of interest.

At first sight of the phenomenon one is reminded of the production of spectra by allowing the spark to pass from a platinum point *to* a solution of a metallic salt, and the spectra do show marked similarity to those produced in this way. The researches on the mechanism of the interrupter have shown, however, that the breaking of the circuit is caused by the formation of a layer of vapor about the active point, and that the water of the solution is in large measure dissociated by the high temperature reached.[1] There seemed, therefore, the possibility that we might possess in an arrangement of this kind another step in our scale of spectra, and possibly a temperature midway between that of flame and arc, or arc and spark.

[1] See VOLLER and WALTER, *loc. cit.*

The importance of a more thorough study of spectra produced under water and in gases and vapors under pressure, and the fact that among von Bolton's drawings of spectra of the Wehnelt interrupter there are several which are ***banded***, gave interest to a more exact study of the phenomena.

In order to reach some degree of accuracy in the comparison of wave-lengths, the spectra were photographed with a Rowland concave grating of 163 cm radius, of about 2,500 lines to the cm. This grating has a ruled surface of 8×14.5 cm, and gives a very bright spectrum indeed. The dispersion is of course small, the length of the first spectrum from $\lambda 3200$ to $\lambda 6000$ being only about 5 cm. This grating was kindly loaned us by Professor Langley, and has proved indispensable for the work.

The instrumental arrangements were simple. The Wehnelt cell was made of a beaker, the large electrode was of platinum, lead, or aluminium, and the point was a wire of the metal under investigation, or, where the metal was in solution as a salt, of platinum or carbon. In this latter case the platinum lines or the lines of impurities in the carbons used often appeared, and they were used as standards with which to compare the spectrum sought. The lines of the metal forming the large plate also appeared after a prolonged exposure. The image of the light about the point was focused on the slit by means of a condensing lens of aperture sufficient to fill the whole of the large grating with light.

The exposures required were long, as the light is at best weak compared with that of the spark or arc, of even that of a Geissler tube. For a slit-opening of 0.10 mm the exposure in the first spectrum was from one to two hours. In the third spectrum, where photographs were taken for the more accurate comparison of wave-lengths, the exposure reached six hours, the intensity of the light varying greatly with different metals.

The spectra were photographed on orthochromatic plates, without color screen, and the range of most of the photographs is from $\lambda 3200$ to $\lambda 6000$. In some cases the photograph extends much farther into the red, the line of lithium at $\lambda 6709$ being, for example, clearly visible. The plates were developed with amidol,

to which only a very small amount of sodium sulphite and a little potassium bromide were added. This developer acts slowly, but permits of prolonged development without the production of chemical fog. It is to be highly recommended for work of this kind, where under-exposure is the rule and every possible detail must be obtained from the plate.

During the exposure the light was observed frequently with a direct-vision spectroscope, and the various parts of the glowing gaseous envelope about the point were examined in the hope of finding differences in the spectrum at various points. Such differences were not found, the spectrum being apparently the same in all parts of the envelope and remaining remarkably constant throughout the exposure.

As the electrolyte became hot, the intensity of the light became less, and for the sake of economy in time the solution was usually changed every ten or fifteen minutes. The points of most of the metals used also required frequent replacing, and this was done by feeding the wire down through a simple clamp as fast as it was eaten away.

The first series of observations showed that the spectrum is exactly the same, whether the metal in question is used as active electrode or is present as a salt in solution; further, whether the metallic point is anode or cathode, though a great difference in the intensity of the light exists in the two cases. The metallic point as anode gives only a feeble zone of light. As cathode several distinct stages of the condition about the point are to be distinguished, one of these being accompanied by a rapid *Zerstäubung* of the metal. This condition is unfavorable for the production of a bright luminescence, but goes over with increase of current density into the more favorable condition.

It was found that the spectrum is exactly the same whether produced by direct or alternating current. With direct current the electrolyte heated faster and the point was more rapidly eaten away. The greater part of the work was therefore carried out with the commercial alternating current, which is of 110 volts and 60 cycles. The current through the cell averaged 2.5 amperes, and it was found best to keep the resistance of the

electrolyte at a point which would give about this current. The large plate had a contact surface of about 10 sq. cm, and the wires used were of diameter 0.3 to 1.5 mm.

No direct experiment on the effect of inductance in the circuit was made, but the cell was used alternately without inductance and as interrupter with a large induction coil for the production of the spark spectra, without any change being visible in the small direct-vision spectroscope.

It was expected that many gaseous lines would appear, and they were looked for, but the only one found under the conditions of the experiment was the red hydrogen line at $\lambda 6562$.[1] This is visible clearly in many cases; in others it is either very faint or entirely invisible.

In the following tables the wave-lengths of the principal lines are given, with their intensities in the spark, arc, and Wehnelt spectra on a scale of 1 to 100; 1 being the intensity of a barely measurable line, and 100 that of very strong lines like the principal lines of the alkali- and alkaline earth-metals. It is, of course, clear that such intensity measurements with the eye, on plates where the exposures are by no means comparable, are only rough approximations. The attempt has therefore been made to confine any conclusions drawn from such comparisons to cases so obvious and striking that there could be no possible chance of error introduced by difference in exposure or width of slit.

Careful comparison of the spectra produced by a platinum or carbon point in solutions of various salts of the same metal shows that there are no differences whatever corresponding to different salts. This has been proved for zinc by photographing the spectrum of a platinum point in zinc sulphate, nitrate, chloride, bromide, and iodide, and also that of a zinc point in sulphuric, nitric, and hydrochloric acids. These spectra are all identical within the limits of the method. The same has been shown for aluminium for an equally extended series of salts and acids, and in the cases of other metals for a less number of combinations. The tables

[1] WERNER VON BOLTON, *loc. cit.*, used the hydrogen lines of the Wehnelt as standards for comparison, and shows them in his drawings of spectra. Certainly none appear on any of the author's plates.

give the data for a stated combination in each case, but apply equally well to any other for the same metal or for any salt of the same metal.

The present paper is concerned only with the photographs of the Wehnelt in the first spectrum, where comparison can be made with the full spectrum of spark and arc without disturbance from overlapping. The dispersion is only sufficient to give an accuracy of about 1 Ångström unit in the comparison of wave-lengths.

LITHIUM.

(Plate XVII, Fig 1.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3233.0......	6	10	2	4273.5.......	5	30	5
3795.0......	..	5	..	4602.5.......	100	100	100
3915.0......	..	8	..	4972.0.......	40	50	15
3986.0......	..	8	..	6104.0.......	10	20	30
4132.5......	15	100	10	6708.0.......	..	2 rev	5

Spark—Lithium chloride on carbon electrodes.

Arc—Lithium chloride on carbon electrodes.

Wehnelt—Carbon point in solution of lithium chloride. (The impurities in the carbon are iron, calcium, and aluminium.)

It seems probable that the exposure of the Wehnelt is at least as great in proportion as the others, since the line at $\lambda 6708$ comes out clearly, and lines of shorter wave-length than $\lambda 3233$ are visible.

The resemblance to the spark spectrum is striking, but there are considerable differences in intensities, $\lambda 4972$ being much weaker and $\lambda 6104$ much stronger. Many of the strong *arc* lines are either absent or greatly reduced in intensity. It is of interest to note that the lines which retain a part of their intensity belong to the principal and first sub-series of Kayser and Runge, while those which lose all or a great part of their intensity from arc to Wehnelt belong to the second sub-series. The lines at $\lambda 4972.0$, $\lambda 4273.5$, $\lambda 3986.0$ are of this latter class.

SODIUM.

(Plate XVI, Fig. 2.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3303.0......	15	40	10	5688.0.......	15	40	30
4983.0*d*.....	..	10	..	5890.0.......	50	50 rev.	50
5155.0*d*.....	..	4	..	5896.0.......	40	40 rev.	50
5682.5.....	15	15	10				

Spark — Sodium chloride on carbon electrodes.

Arc — Metallic sodium on carbon electrodes.

Wehnelt — Carbon point in solution of sodium hydroxide. (Impurities same as in lithium.)

A rather close agreement with the spark spectrum is to be seen, with a noticable difference in the relative intensities of the lines at $\lambda 5682$ and $\lambda 5688$. The lines which are present in the arc spectrum and do not appear in the Wehnelt spectrum belong in this case also to the second sub-series, but it is quite probable that the exposure was insufficient to bring out these relatively weaker lines. $\lambda 5896$ is at least as strong as $\lambda 5890$. Taking into account the rapid decrease in the sensitiveness of the plates in this region, it must in reality be stronger.

POTASSIUM.

(Plate XVI, Fig. 3.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3217.5......	..	3	..	5340.0.......	2	20	6
3447.0......	..	40	20	5343.5.......	1	..	..
4044.5......	{ 30	100	100	5359.5.......	..	15	6
4047.0......	{ ..	..	..	5783.0.......	3	20	6
5099.5......	..	4	1	5802.0.......	3	20	10
5112.5......	..	3	1	5812.5.......	..	3	1
5323.5......	2	10	3	5832.0.......	2	10	6

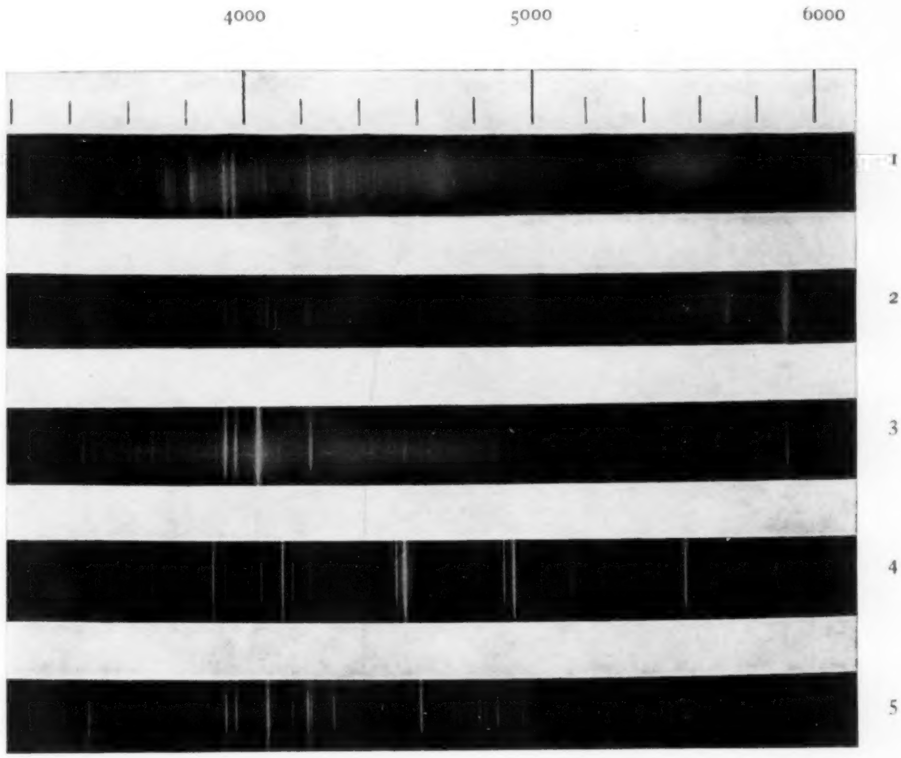
Spark — Potassium chloride on carbon electrodes.

Arc — Metallic potassium on carbon electrodes.

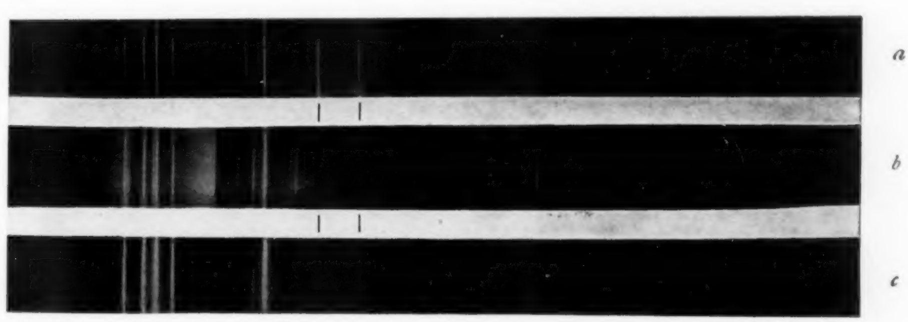
Wehnelt — Carbon point in solution of potassium carbonate. (Impurities in carbons same as in lithium.)

The spectrum resembles the arc more closely than the spark. The difficulty of obtaining the spark spectrum unobstructed by

PLATE XVI.



1. Carbon point in hydrochloric acid.
2. Carbon point in sodium hydroxide solution.
3. Carbon point in potassium carbonate solution.
4. Platinum point in barium chloride solution (impurity, lead.)
5. Platinum point in strontium chloride solution.



6. (*a*) Spark between lead electrodes.
   (*b*) Arc. Metallic lead on carbon electrodes.
   (*c*) Lead wire in hydrochloric acid.

air lines and the lack of a resolution of the doublets make comparisons in the case of little value.

MAGNESIUM.

(Plate XVII, Fig. 2.)

Wave-Length	Spark	Arc	Flame	Wehnelt	Wave-Length	Spark	Arc	Flame	Wehnelt
3330.0.....	7	8	....	7	4966.5....	..	..	....	4
3332.5.....	10	10	....	10	4974.5....	..	..	....	*b*
3337.0.....	12	15	....	12	4984.5....	..	..	....	*b*
3341.0.....	..	..	....	2	4995.0....	..	..	....	*b*
3437.5.....	15	..	....	..	5006.0....	..	..	....	*b*
3720.0.....	..	..	strong	10	5020.0....	..	..	....	*b*
3724.0.....	..	..	strong	15	5028.3....	..	..	....	*b*
3730.0....	..	..	strong	20	5036.0....	..	..	....	*b*
3829.5.....	20	10	strong	20	5063.0....	..	..	....	*b*
3832.5.....	30	15	strong	30	5072.0....	..	..	....	*b*
3838.5.....	40	20	strong	40	5079.5....	..	..	....	*b*
3855.0.....	..	..	....	1	5086.5....	..	..	....	*b*
4352.0.....	3	12	....	5	5168.0....	..	20	....	20
4443.5.....	..	..	....	b	5172.5....	5	30	....	30
4449.0.....	..	..	....	b	5183.0....	5	50	....	50
4481.0.....	30	..	....	30	5527.5....	4	...	....	3
4570.0.....	..	1	strong	..	5529.0....	..	20	....	..
4704.0.....	4	15	....	6	5711.0....	..	3	....	..
4960.5.....	..	..	....	10	5880.0....	..	..	....	*b*

Spark — Magnesium terminals.
Arc — Metallic magnesium on carbon electrodes.
Flame — Liveing and Dewar's measurements.
Wehnelt — Magnesium wire in hydrochloric acid.

In the above table the following points are of especial interest:

1. The triplet λ 3720, λ3724, λ3730. These lines do not appear in the spark or arc spectrum under ordinary circumstances, but are strong in the spectrum of magnesium in the oxy-hydrogen flame, and have always been considered lines belonging to a low temperature. Liveing and Dewar[1] observed that when the arc passed between electrodes of metallic magnesium, these lines were visible, provided the atmosphere about the arc was one which could provide oxygen. They come out clearly in air, oxygen, and carbon dioxide, but do not appear in hydrogen, nitrogen, cyanogen, chlorine, or ammonia.

[1] *Proc. R. S.*, **32**, 189, 1881; **44**, 241, 1888.

2. The presence of the arc line at λ 4352 and the strong spark line at λ 4481. One or the other of these is usually very faint under ordinary conditions. In the arc between magnesium electrodes both lines are strong, λ 4481 sometimes quite as strong as in the spark. Hartmann and Eberhard[1] have shown that in the spectrum of the arc between magnesium terminals under water, spark lines become strong, λ 4481 showing clearly. Hartmann[2] has also shown that there is reason to doubt that λ 4481 corresponds to a higher temperature than λ 4352. The spectrum of the arc between magnesium terminals in an atmosphere of hydrogen is nearly identical with that produced under water.

3. The absence of certain strong lines in the Wehnelt spectrum; among these the arc line λ 5529, the flame line λ 4570, the spark line λ 3437.5. The presence of other lines usually appearing, and supposed to correspond to the same temperature, is also of importance.

4. The presence of the bands usually ascribed to the oxide. In the band with head at λ 5006 seven flutings are visible. These are also visible in the arc spectrum, but are much fainter. This band was described by Liveing and Dewar (*loc. cit.*) and resolved into fine lines by Crew and Basquin.[3] The first-named authors obtained the band only in oxygen, air, or carbon dioxide; and the evidence seems to show conclusively that it is due to the oxide. It seems clear from Liveing and Dewar's work that the presence of this band does not necessarily indicate a lower temperature than that corresponding to the other lines of the spectrum of magnesium. This band also appears when the spark is allowed to pass from a platinum point to a solution of a magnesium salt.[4]

5. The *appearance* of certain lines. The line at λ 4481 is perfectly sharp, as it is when inductance is introduced into the circuit of the spark in air.[5] The triplet λ 3829.5, λ 3832.5, λ 3838.5 is very intense, and the lines are broadened and diffuse in contrast with their appearance in air. Wilsing[6] finds that when the

[1] Astrophysical Journal, **17**, 229, 1903.

[2] *Ibid.*, **17**, 270.

[3] *Ibid.*, **2**, 101, 1895.

[4] See Lecoq de Boisbaudran, *Spectres Lumineux*.

[5] See Huggins, Astrophysical Journal, **17**, 145, 1903.

[6] *Ibid.*, **10**, 113, 1899.

PLATE XVII.

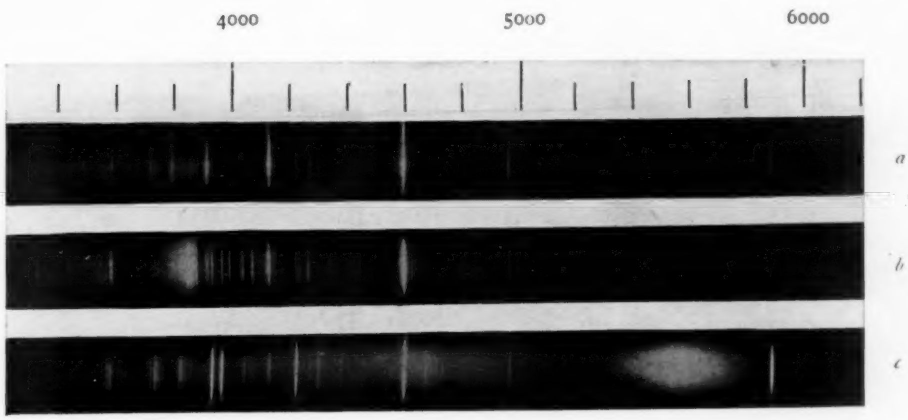


FIG. 1.—(*a*) Lithium chloride. Arc spectrum.
(*b*) Lithium chloride. Spark spectrum.
(*c*) Carbon point in lithium chloride solution.

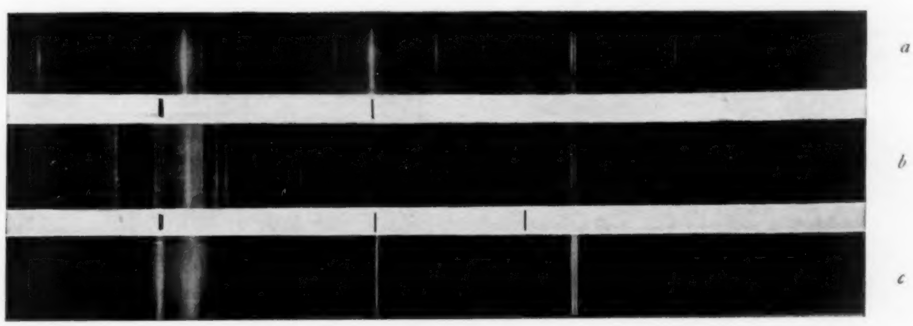


FIG. 2.—(*a*) Spark between magnesium terminals.
(*b*) Arc. Metallic magnesium on carbon electrodes.
(*c*) Magnesium wire in hydrochloric acid.

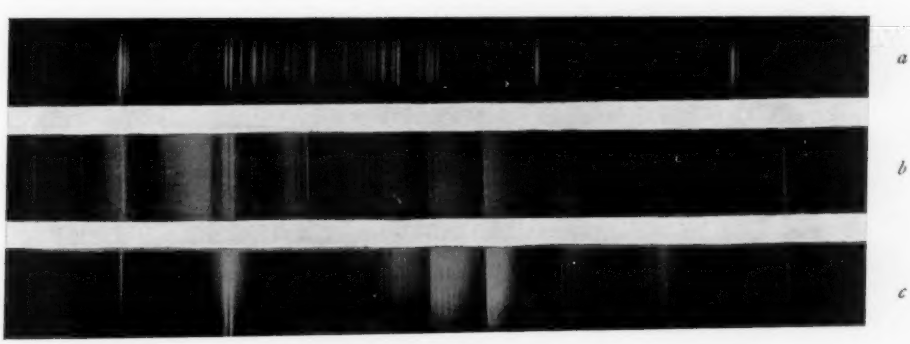


FIG. 3.—(*a*) Spark between aluminium terminals.
(*b*) Arc. Metallic aluminium on carbon electrodes.
(*c*) Aluminium wire in hydrochloric acid.

arc passes between magnesium terminals under water, this triplet is displaced, and broadens out into diffuse absorption bands.

CALCIUM.

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3179.5......	20	..	..	4878.5......	5	8	..
3275.0......	..	8	..	5041.5......	3	4	..
3631.0......	5	30	2	5189.0......	3	4	..
3644.5......	10	20	2	5262.5......	3	4	3
3706.5......	50	10	20	5265.7......	2	6	2
3737.5......	50	25	30	5270.5	5	10	..
3933.5......	100	100	60	5349.5......	3	5	..
3968.5......	60	70	40	5472.0......	..	2	*b?*
4227.0......	40	100	30	5509.0......	2	3	*b?*
4283.0......	6	10	5	5537.0......	..	..	*b?*
4289.5......	4	10	5	5582.0......	3	6	*b?*
4299.0......	3	5	3	5589.0......	10	10	15
4302.5......	5	8	8	5594.0......	4	6	*b?*
4308.0......	3	8	3	5598.5......	4	4	*b?*
4319.0......	7	10	3	5601.5......	3	3	*b?*
4425.5......	7	15	3	5603.0......	3	2	*b?*
4435.5......	10	20	8	5857.5......	..	5	4
4455.0......	15	30	15				

Spark — Calcium chloride on carbon electrodes.
Arc — Calcium chloride on carbon electrodes.
Wehnelt — Platinum point in calcium chloride solution.

The spectrum is very like that of calcium in the spark, with many differences of intensity, and absence of some fairly strong lines. The spectrum from λ 5500 to λ 5900 is of interest. There is evident diffuseness in the lines in this region, in marked contrast to the sharp lines of the spark and arc; but whether this is due to a real difference in the spectra or a possible lack of adjustment of the apparatus, a more extended investigation must decide. So far as the plates obtained show, there are bands with heads corresponding to sharp lines in the arc and spark spectra.

STRONTIUM.

The spectrum is in general similar to that of the spark, the order of intensities agreeing well in the majority of instances. A few of the stronger spark lines, with intensities sufficient to make them visible if they were present in normal intensity, are

STRONTIUM.

(Plate XVI, Fig. 5.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3381.0......	30	8	5	4869.0.....	4	..	..
3465.0......	40	10	20	4874.0.....	5	5	5
3475.0......	10	8	3	4893.0.....	2	..	..
3706.0......	..	10	3	4962.0.....	7	8	3
4030.0......	..	8	..	4968.0.....	2	4	..
4078.0	100	50	50	5221.5.....	2	..	..
4162.0......	15	5	6	5224.0.....	2	..	..
4215.5......	100	40	40	5238.5.....	2	5	..
4303.0......	..	2	..	5256.5.....	3	5	..
4306.0......	40	4	20	5456.5. ...	3	..	..
4319.0......	..	8	..	5480.5.....	8	..	..
4438.0	..	30	..	5485.0.....	1	..	*b?*
4531.5......	..	5	..	5504.0.....	6	..	*b?*
4607.5......	25	50	30	5520.5.....	4	..	..
4722.5......	5	10	5	5534.0.....	20	..	*b?*
4742.0......	5	10	3	5540.0.....	3	..	..
4784.0......	3	8	2	5587.0.....	..	..	*b?*
4812.0......	7	10	6	5850.0.....	4	..	..
4832.0......	6	10	3	5890.0.....	..	..	*b?*
4855.0......	2	..	..	5895.0. ...	..	..	*b?*

Spark—Strontium chloride on carbon electrodes.
Arc—Strontium chloride on carbon electrodes.
Wehnelt— Platinum point in solution of strontium chloride.

not to be seen. Among these are the group λ 5225–λ 5257. The "oxide" bands are bright.

The same question arises here as in the case of calcium. In the Wehnelt spectrum of strontium there are diffuse bands in the yellow and yellow-green with maxima which seem to correspond closely with sharp lines in the spark spectrum. Whether or not greater dispersion will show these to be really bands with heads in the same places as are occupied by sharp lines in the other spectra, the plates at hand give insufficient evidence. A more exact study of these bands and the similar ones in the calcium spectrum offers great interest.

The following comparison table for barium does not include the bands in the green, which are strong in the spectrum of the Wehnelt:

BARIUM.

(Plate XVI, Fig. 4.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3377.0......	..	8	..	4674.0.....	2	5	2
3420.5......	..	10	6	4691.0.....	1	5	..
3501.0.....	5	15	..	4727.0.....	1	10	..
3525.0......	..	6	..	4900.0.....	30	..	30
3545.0......	..	6	..	4903.0.....	..	10	..
3892.5......	50	8	50	4934.0.....	80	30	100
3910.0......	..	8	2	5160.0.....	..	10	..
3993.5......	5	15	3	5424.0.....	..	40	5
4131.0......	40	40	60	5519.0.....	5	30	6
4166.0......	15	10	15	5534.0.....	20	80	100
4283.5......	..	20	3	5620.0.....	..	10	..
4351.0......	..	20	2	5680.0.....	..	8	..
4403.0......	3	10	3	5778.0.....	..	50	5
4432.0......	3	8	5	5800.5.....	..	10	..
4506.0......	2	4	4	5826.0.....	..	10	2
4525.0......	30	30	30	5854.0.....	8	10	8
4554.0......	100	100	100	6142.0.....	..	2	5
4580.0......	..	5	4				

Spark — Barium chloride on carbon electrodes.

Arc — Barium chloride on carbon electrodes.

Wehnelt — Platinum point in solution of barium chloride.

The following table gives the approximate position of these bands:

BANDS IN THE WEHNELT SPECTRUM OF BARIUM.

Wave-Lengths		Wave-Lengths	
4570.0 to 4575.0		5272.0	(red edge of same fluting)
		5325.0	head of fluting (red edge)
4598.0 to 4605.0		5446.0 to 5462.0	
		5477.0	center of band
5134.0	center of band	5497.0 to 5519.0	(line; intensity 6)
5167.0	center of band		
5242.0	head of fluting (violet edge)		

The spectrum produced about a platinum point in a solution of barium chloride is in many points similar to the spark spectrum. Many arc lines, absent from, or extremely weak in, the spark spectrum make their appearance. λ 3910.0, λ 4283.0, λ 4351.0, λ 4580.0, λ 5425.0, λ 5778.0, are examples. At the same time, many strong arc lines are absent in the Wehnelt

spectrum, which has the appearance of a rather incomplete composite of arc and spark spectrum, so far as the *line* spectra are concerned. The brightness of the "oxide" bands in the green is remarkable. Altogether the spectrum of the Wehnelt is much like that produced by sparking from a platinum point to a solution of a barium salt.[1]

ALUMINIUM.

(Plate XVII, Fig. 3.)

Wave-Length	Spark	Arc	Wehnelt
3587.0	50	20	25
3602.0	30	4	4
3612.5	15	...	2
3702.5	2	...	...
3714.0	8	...	2
3944.0	50	60	50
3961.5	100	100	100
4034.3			Heads of flutings in Wehnelt spectrum
4083.7			
4243.2			
4262.5			
4271.8			
4274.0			
4276.6			
4279.3			
4282.7			
4306.8			
4332.0			
4341.7		Heads of flutings in arc spectrum	
4354.3			
4371.7			
4375.6			
4384.6			
4395.6			
4414.8			
4432.5			
4448.0			
4464.0			
4472.0			
4480.0			
4495.3			
4512.2			
4517.7			
4530.0			
4538.7			
4558.9			
4577.6			
4595.0			
4608.4			
4625.9			
4642.3			

Wave-Length	Spark	Arc	Wehnelt
4648.5		Second band heads	Second band heads
4662.8			
4671.9			
4695.2			
4717.1			
4736.9			
4755.1			
4782.6			
4803.3			
4817.8			
4842.0		Third band heads	Third band heads
4861.0			
4866.6			
4889.6			
4951.6			
4960.1			
4980.1			
4994.0			
4999.5			
5011.0			
5017.8			
5080.6		Fourth band heads	Fourth band heads
5093.3			
5102.7			
5111.4			
5118.1			
5124.0			
5142.6			
5148.0			
5161.0			
5176.0			
5190.0			
5202.0			
5207.6			
5222.4		Bands	Bands
5328.5			
5337.0			
5465.0			
5593.0		5	5 Lines
5697.0		3	3
6234.0		..	3
6244.0		..	5

[1] See Lecoq, *loc. cit.*

The spectrum of an aluminium point as active electrode in an acid or an alkali or a salt solution, and that from a platinum point in a solution of an aluminium salt, seem to be exactly the same as that obtained by allowing a spark discharge without condenser to pass in air between aluminium terminals. The author has obtained the same banded spectrum in tubes containing oxygen at a pressure of a few millimeters of mercury, and with the same distinctness in tubes containing hydrogen at low pressures, by allowing the spark, condensed or uncondensed, to pass between aluminium terminals. In the case of tubes filled with hydrogen the bands persist for only a comparatively short time, and the spectrum of hydrogen remains. The same spectrum, with the exception of some lines not belonging to the bands, is obtained from aluminium in the arc.

Hasselburg[1] has measured a great number of lines in these flutings, and his measurements have been used for comparison, the agreement being as close as could be expected from the small dispersion and poor definition of the plates measured.

These bands have been for many years attributed to the oxide, but there exists a considerable amount of evidence contradictory to this view. Arons[2] found this same banded spectrum in the arc between aluminium points in an atmosphere of nitrogen or hydrogen, and concluded that the banded spectrum corresponds to the metal and not to the oxide. Hemsalech[3] agrees with Arons, and he has shown that by introducing inductance the line spectrum of the spark between aluminium terminals in nitrogen changes into this same banded spectrum. Berndt[4] concludes from his experiments that the presence of oxygen is necessary for the production of the bands. Lockyer also attributes the bands to the oxide, Wüllner to the metal, Kayser to the oxide, etc.[5] Simple experiments of the author in hydrogen and oxygen in closed tubes have shown that the band spectrum, which is present in considerable strength when the discharge is first sent through the tube, decreases rapidly and disappears in a short time in hydrogen, to appear again after the tube has been allowed to recover for a time. The simplest apparent explana-

[1] *Kon. Svensk. Akad.*, 24. [2] *Annalen der Physik*, 1, 700, 1900.

[3] *Ibid.*, 2, 331, 1900. [4] *Ibid.*, 4, 788, 1901. [5] See references, HEMSALECH, *loc cit.*

tion is that the oxide coating of the aluminium terminals reacts with the hydrogen under the influence of the spark with the formation of water vapor, probably until equilibrium between metallic aluminium, aluminium oxide, hydrogen, and water vapor is reached. On standing the oxide is re-formed and the equilibrium at the lower temperature re-established.

The tendency, already spoken of under barium, toward a composite of arc and spark spectra is very evident in the case of aluminium. Not only are the bands and lines of the arc spectrum present, but also several lines which do not belong to it.[1] Most of the lines of the spark spectrum are present in the Wehnelt, some of them with changed intensities. The general appearance is as though a rather weak spark spectrum had been superimposed over a stronger arc spectrum.

It is the intention of the author to return to this and other band spectra of the Wehnelt in a later paper. The intensity of the light from an aluminium point in hydrochloric acid is sufficient to permit of a photograph with a grating of higher dispersion without an excessively long exposure. The spectrum being free from the overlapping carbon bands of the arc, the long band in the violet, which was not examined by Hasselberg, should be very easy of access.

SILVER.

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3281.0......	60	50	30	3982.0	..	3	..
3330.0......	..	..	2	4055.5	1	15	5
3358.9......	..	..	2	4212.0	1	10	10
3383.0......	60	50	50	4228.5	..	..	1
3546.5......	..	2	1	4312.0	1	..	1
3583.0......	..	2	2	4476.0	1	12	8
3639.5......	..	..	1	4668.5	..	15	10
3682.0......	1	15	1	4875.0	1	..	1
3781.0......	..	..	1	5209.0	100	50	40
3811.0......	..	..	1	5402.0	20	..	..
3892.0......	4	..	..	5465.0	..	50	100
3907.5......	..	1	1	5471.5	..	20	..
3943.0......	1	1	..	5709.0	10	..	..
3963.0......	..	..	2				

Spark — Silver electrodes.
Arc — Metallic silver on carbon electrodes.
Wehnelt — Silver wire in hydrochloric acid.

[1] See KAYSER and RUNGE, *Wied. Ann.*, **48**, 126.

With silver as active electrode striking differences of intensity from those obtained in the spark and arc are the rule. Only a few lines come out strongly enough to be reproduced, and the spectrum is in general more like that of the arc than that of the spark. This is shown by the lines at λ 4055.5, λ 4212.0, λ 4476.0, λ 4668.0, λ 5465.0. A number of lines which are strong in the arc are not visible, as, *e. g.*, λ 5471.0, and others are much weaker, like λ 3682.0.

Traces of what appears to be an underlying band spectrum are visible, but the maxima are of such small intensity that a very long exposure would be required to bring out the structure clearly. Such maxima as could be distinctly seen have been placed in the Wehnelt column of the table of wave-lengths.

ZINC.

(Plate XVIII, Fig. 1.)

Wave-Length	Spark	Arc	Wehnelt	Wave Length	Spark	Arc	Wehnelt
3282.5......	20	20	10	4680.5	30	40	40
3302.5......	30	30	15	4722.5	40	50	50
3345.5......	40	50	20	4811.5	50	60	60
3683.5......	..	30	8	4911.5	30	..	8
4058.0......	..	25	5	4924.0	40	..	5
4630.0......	..	10	3				

Spark — Zinc electrodes.
Arc — Metallic zinc on carbon electrodes.
Wehnelt — Zinc wire in hydrochloric acid.

Besides the above lines there are present in the spectrum of the Wehnelt the lines of an underlying band spectrum with heads at approximately λ 3848.0, λ 4238.0, λ 4257.0, λ 4299.0, 4325.0. The finer detail of these bands, from photographs in the third spectrum, will be given in a later paper. The heads of the flutings of the strongest and longest band have wave-lengths as follows:

4163.2	4203.9	4232.2	
4170.1	4208.0	4237.8	
4176.5	4212.9	4242.4	
4182.4	4216.1	4247.8	
4187.6	4220.2	4252.5	
4193.7	4226.7	4256.9	Head
4199.6			

The spectrum of a zinc point used as active electrode offers many interesting differences from the spark and arc spectra of the metal.

1. The triplets λ 3282.5, λ 3302.5, λ 3345.5, and λ 4680.0, λ 4722.0, λ 4811.0, are present with about the same relative intensities as in spark and arc. The lines λ 3683.0, λ 4059.0, λ 4630.0, which are strong in the arc and absent from the spark, are present in the Wehnelt spectrum with lower intensities, but have about the same ratio of intensity as in the arc. The lines λ 4911.0 and λ 4924.0, strong *spark* lines which are absent from the arc spectrum, are present in the Wehnelt, but with less intensity, and are not decreased proportionately.

2. These two lines, λ 4911.0 and λ 4924.0 belong to a class which will be referred to again under tin and lead, broad and diffuse, and distinctly different from the other lines of the spark in appearance. The position of these lines in Kayser and Runge's series[1] has not been determined, and the question as to whether they belong to the same class as the tin lines noticed by Crew[2] is still an open one.

3. The marked underlying band spectrum. This is so faint as to be difficult of reproduction, though a large part of it may be measured, especially the brighter band from λ 4163.0 to λ 4257.0. Here nineteen maxima are visible, but it is in many cases difficult to decide whether lines or the heads of flutings are being measured. These bands seem to be characteristic of this method of producing a zinc spectrum, and the author knows of no other notices or measurements of them.

MERCURY.

The Wehnelt seems to lie about half-way between the arc and the spark in relation of intensity of lines. λ 3278.0 is plainly visible, though of lowest order of intensity in the spark and invisible in the arc spectrum. The lines at λ 3650.0, 3655.0, and λ 3663.0 have about the same intensities as in the spark. λ 3984.0 is very feeble, of intensity 4 in the table, as against 40 for the next line, λ 4046.0, and 6 for λ 4078.0. The arc line at

[1] See *Wied. Ann.*, 43, 395, 1894. [2] ASTROPHYSICAL JOURNAL, **12**, 167, 1900.

PLATE XVIII.

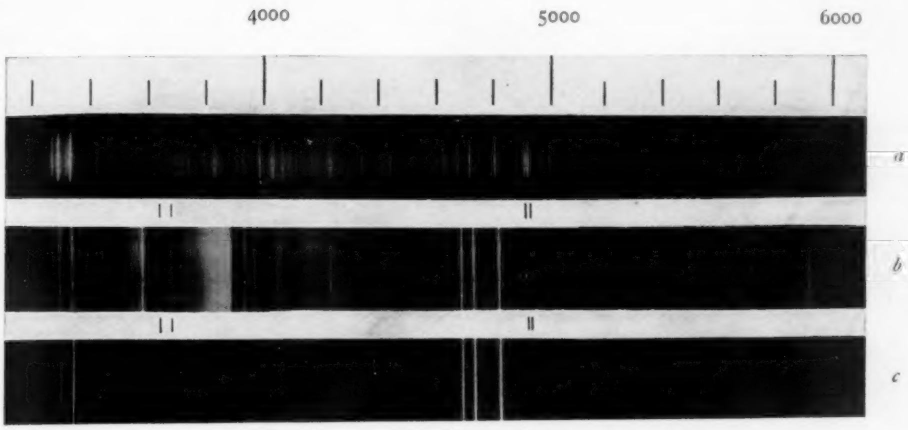


FIG. 1.—(*a*) Spark between zinc terminals.
(*b*) Arc. Metallic zinc on carbon electrodes.
(*c*) Zinc wire in hydrochloric acid.

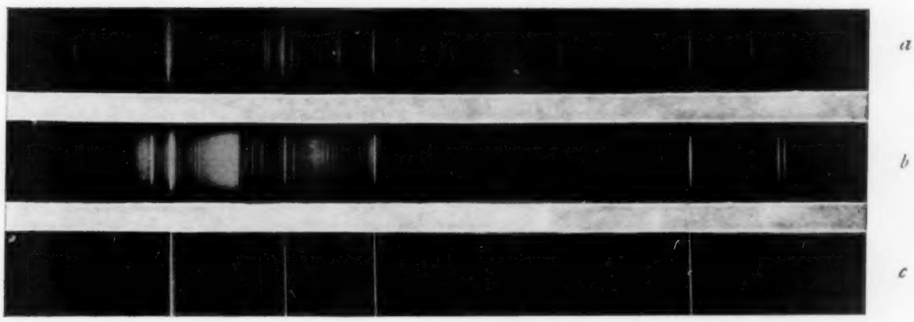


FIG. 2.—(*a*) Spark between amalgamated copper electrodes.
(*b*) Arc. Metallic mercury on carbon electrodes.
(*c*) Platinum point in mercuric chloride solution.

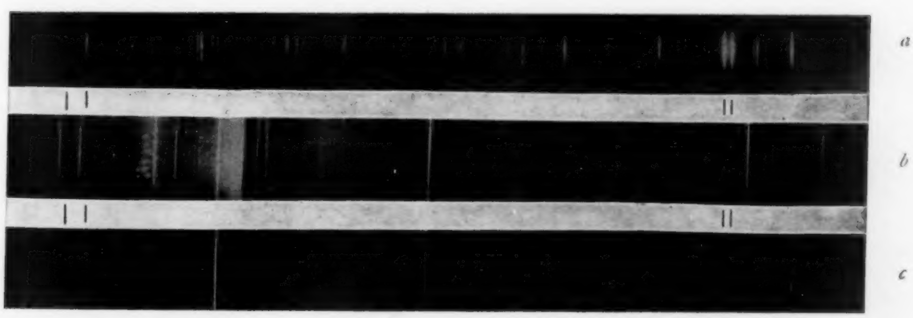


FIG. 3.—(*a*) Spark between tin electrodes.
(*b*) Arc. Metallic tin on carbon electrodes.
(*c*) Tin wire in hydrochloric acid.

MERCURY.

(Plate XVIII, Fig. 2.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3278.0......	1	..	3	4348.0	..	7	3
3342.0......	7	20	..	4359.0	30	40	40
3381.0......	..	..	10	4916.5	..	5	2
3543.5......	1	6	..	5217.0	2	..	..
3650.5......	50	15	50	5426.0	10	..	..
3655.0......	5	10	8	5461.0	50	100	50
3663.0......	7	15	10	5595.0	3	..	..
3681.0......	..	8	..	5678.0	20	..	..
3984.0......	40	5	4	5769.0	20	50	20
4047.0......	30	20	40	5790.0	20	50	20
4078.0......	2	15	6				

Spark — Amalgamated copper terminals.
Arc — Metallic mercury on carbon electrodes.
Wehnelt — Platinum point in solution of mercuric nitrate.

λ 4916.5 is plainly visible, while the line at λ 3681.0, also belonging to the arc spectrum, is not to be seen. The spark lines at λ 5426.0 and λ 5678.0 are not present. There is a strong line at λ 3381.0 in the spectrum of the Wehnelt which has not been placed satisfactorily to the credit of any impurity. No traces of a banded spectrum are to be seen.

TIN.

The points of especial interest in the following table are:

1. Marked differences in intensities in spark, arc, and Wehnelt spectra. λ3283.5 and λ5332.0 are much weaker in the last than in the spark, and λ3330.0, λ3655.5, λ3801.0, λ4525.5, λ5632.0 are much stronger. The spectrum of the Wehnelt is in many parts more like that of the arc.

2. The presence of an underlying band spectrum, containing many flutings, and not present either in the spark or the arc spectrum of the metal. The wave-lengths of these maxima have been placed in the table, without certainty as to whether the maximum in question is a sharp line or the head of a fluting. So far as the author knows, this spectrum of tin has not been observed under any other circumstances.

3. The *appearance* of certain lines. Of striking interest in

TIN.

(Plate XVIII, Fig. 3.)

Wave-Length	Spark	Arc	Wehnelt		Wave-Length	Spark	Arc	Wehnelt	
3175.0......	2	3	2		3821.5......	..	..	1	Heads?
3249.0......	..	..	4		3837.5......	..	..	2	
3262.5......	15	10	20		4046.5......	..	..	1	
3273.5......	..	..	3		4307.5......	..	..	1	
3283.5......	20	..	3		4382.5......	..	..	2	
3330.5......	3	10	30		4512.0......	..	..	1	
3352.0......	30	..	8		4525.5......	8	40	100	
3392.0......	..	..	1	Heads of flutings?	4586.0......	10	..	1	
3416.5......	..	..	1		4617.3......	..	..	2	Heads?
3446.5......	..	..	1		4651.5......	..	..	1	
3472.5......	..	..	1		4722.0......	..	..	1	
3487.3......	..	..	4		4810.0......	..	..	1	
3571.5......	..	..	1		4858.0......	10	..	5	
3589.0......	..	..	4		4923.0......	2	..	..	
3619.0......	..	..	1		5100.5......	8	..	2	
3639.0......	..	..	8		5147.5......	..	..	1	
3655.5......	1	8	10		5223.0......	4	..	..	
3693.2......	..	..	1	Heads?	5243.5......	..	..	1	
3723.4......	..	..	2		5290.0......	2	..	..	
3734.9......	..	..	2		5332.0......	50	..	7	
3746.0......	1	..	1		5562.0......	100	..	20	
3801.0......	15	30	80		5588.0......	100	..	15	
					5632.0......	..	10	10	
					5798.0......	50	..	10	

Spark — Tin electrodes.
Arc — Metallic tin on carbon electrodes.
Wehnelt — Tin wire in hydrochloric acid.

this connection is the pair of lines at λ5562.0 and λ5588.0. These lines are strong in the spark, absent from the arc, and of small intensity in the Wehnelt spectrum as compared with the spark. They are also the most striking lines in the spark spectrum on account of their marked breadth and diffuseness. The lines at λ3283.5 and λ3352.0 have the same peculiarities in a much less degree, and they also follow the same course in their varying intensities in the three spectra.

A similar change in the latter pair of lines has been observed in the arc between tin electrodes in an atmosphere of nitrogen, these lines being much weaker than in the spark in air.[1] In ammonia gas and hydrogen they are greatly *enhanced*. The possibility of the formation of metal-hydrogen compounds in the

[1] See PORTER, ASTROPHYSICAL JOURNAL, 15, 274, 1902.

Wehnelt and of a similar influence of the atmosphere of mixed hydrogen and oxygen is suggested, though other cases (see aluminium and magnesium) seem to indicate the preponderance of the action of the oxygen freed by the dissociation of the water vapor.

Some evidence in the matter is given by the research of Crew[1] on the arc spectra of metals in hydrogen. The results which seem to have bearing in this case are:

1. "All lines in the arc spectrum which are affected by hydrogen, whether enhanced or diminished, belong to the spark spectrum also.

2. "Lines which belong to Kayser and Runge's series are unaffected by the change from air to hydrogen."

These conclusions cannot be applied as a whole to the spectra of the Wehnelt, but something very similar to the second of them seems to be true for zinc, tin, and lead (see lead).

LEAD.

(Plate XVI, Fig. 6.)

Wave-Length	Spark	Arc	Wehnelt	Wave-Length	Spark	Arc	Wehnelt
3573.0......	20	20	25	4245.0	100	..	6
3640.0......	20	25	40	4387.0	100	..	5
3671.5......	10	20	8	4478.0	..	10	..
3683.5......	50	20	30	5005.5	6	..	3
3726.0......	..	20	..	5045.0	8	..	..
3740.0......	30	..	25	5201.5	..	5	..
3854.0......	15	..	..	5372.5	10	..	1
4019.5......	10	20	8	5546.0	10	..	1
4058.0......	100	40	50	5588.0	..	3	..
4062.5......	10	8	6	5607.0	10	..	..
4168.0......	10	12	5	6002.0	..	4	..
4242.0......	10	..	..	6020.0	..	..	10

Spark — Lead electrodes.
Arc — Metallic lead on carbon electrodes.
Wehnelt — Lead wire in hydrochloric acid.

The absence of several of the strong lines of the spark spectrum is of interest (λ3854.0, λ4242.0, etc.). The strong pair of spark lines at λ4245.0 and λ4387.0, which is entirely absent from the arc spectrum, is present in the Wehnelt, but with

[1] *Ibid.*, **12**, 167, 1900.

greatly diminished intensity. This pair is one like those already referred to under zinc and tin, differing from the other lines of the spark spectrum in appearance by being broader and more diffuse.

The spectrum of a carbon point in various acids has also been photographed. None of the plates shows any lines or bands which are not directly traceable to impurities in the carbons used. About ninety lines of iron, twelve of calcium, and two of aluminium were measured in one case. These lines were superimposed on a continuous spectrum of considerable intensity, but no bands were observed. (See Plate XVI, Fig. 1.)

Preliminary tests on salts containing complex ions have given results of interest. A carbon or platinum point in a solution of potassium ferrocyanide gives lines of potassium and iron and no new lines. Potassium chromate as electrolyte absorbs all but a small strip of actinic light, but of a dozen lines measured in the vicinity of the D lines, two were lines of potassium and the rest were lines of chromium, the triplet $\lambda\,5204 - \lambda\,5208$ being strong.

Besides the metals described, the following have been photographed in the Wehnelt, both in the first and third spectrum: copper, nickel, iron, gold, palladium, platinum. Data on the measurements of these spectra will be given in a later paper.

As has already been stated, no effect of the anion has been observed at any time. The breaking up of the chromate ion and the appearance of the lines of metallic chromium in the case of potassium chromate, and the fact that all the salts of the same metal gave identical spectra, show this clearly. The facts all point to the high temperature as the cause of the luminescence, and to the probability that the electrolysis plays a purely secondary part.

Although no effect of the anion is observed, the spectra produced by this arrangement are in many cases compound spectra, if we are to accept the sharp distinction of *compound* and *metallic* or elementary spectra, as evidenced by the presence or absence of *bands*. Aluminium, magnesium, calcium, barium, give the bands which are ascribed to their oxides, and zinc and tin give fluted spectra which appear to be of the same general type. The

presence of free oxygen and hydrogen at a temperature above the point of dissociation of water affords the possibility of a a strong oxidizing action on any metal, and the opportunity for the exhibition of an oxide spectrum when the dissociation temperature of the oxide in question lies at a point higher than the dissociation temperature of water. That the free hydrogen in the mixture of gases could, under these conditions, form metal-hydrogen compounds[1] seems more than doubtful; yet the variations between Wehnelt and spark and arc in air bear a striking resemblance to the variations in the arc spectra of the same metals in air and hydrogen, and in the latter case the necessity for the assumption of such metal-hydrogen compounds seems to be felt.[2]

Although the spectra under discussion are in many ways similar to those produced by allowing the spark to pass from a metallic point to a solution of a salt, many of the characteristic bands of compounds produced by the latter method are absent in the Wehnelt. Compound spectra, varying from salt to salt, are the rule in the more volatile metals[3] when the spark passes to a solution of one of their salts. The point used gives, in the Wehnelt, all the strong lines of the metal, even of platinum, while in the other method the lines of the electrode are but faint.

The tables and plates show the following general points of especial interest:

1. The lines of the Wehnelt spectra include some which have been usually ascribed to the spark and some which have been ascribed to the arc; usually the spectrum is closely allied to that produced in the spark, but often *some of the strongest lines are missing*. Other researches which give evidence as to the effect of varying conditions on spectrum lines serve to strengthen the conclusion which must be drawn—that there is no sharp boundary between arc and spark, and that the transition from "arc" spectrum to "spark" spectrum is a gradual and continuous one.

2. Under constant conditions a spectrum may contain the

[1] See LIVEING and DEWAR, *loc. cit.*

[2] See BASQUIN, *loc. cit.*, and PORTER, *loc. cit.*

[3] LECOQ, *Spectres Lum.* atlas.

strongest lines of the condensed spark and at the same time lines usually ascribed to the flame.[1]

3. Under the same conditions the "oxide bands" may be present at the same time as the strong spark lines.[1]

4. Under the same conditions the spectrum of zinc contains, besides lines belonging to both spark and arc spectra, a band spectrum not hitherto observed under any conditions. The same is true of the spectrum of tin in the Wehnelt interrupter.

5. Certain lines which are of broad, diffuse appearance in the spark and are absent from the arc spectrum of the metal, are present in the Wehnelt spectrum, but much decreased in intensity. The metals which show this phenomenon most sharply are zinc, tin, and lead.

The first thought is, of course, that we are dealing with a complicated process, involving an entire series of temperatures from that sufficient to give the band spectrum of a compound to that necessary to produce the strongest lines of a difficultly fusible metal like platinum or chromium, and that the point and the space about it pass through this series of temperatures at each interruption of the current. The result would be a spectrum which was the sum of the spectra corresponding to the various temperatures through which the system passes. Such a conclusion should be evidenced by the presence of all the lines of all the spectra, and if we are to couple each spectrum with a definite temperature, we should expect the resulting composite to be complete. But in none of the cases examined are all of the lines of the various spectra present. Some strong lines are, and some are not, present in normal intensity. So this conclusion, though perhaps the simplest consistent with our present knowledge of temperature and spectra, and the relation between them, seems not to explain the facts.

The interrupting action in the Wehnelt is undoubtedly caused by the intense heating due to the high current density about the small point. The heat vaporizes and then dissociates the water into hydrogen and oxygen, as has been shown by the analyses

[1] See on these points LIVEING and DEWAR, *loc. cit.*; also *Proc. R. S.*, **32**, 189, 1881.

of Voller and Walter (*loc. cit.*) and others. That spectra like those of the oxy-hydrogen flame should result from the explosion of the mixed gases by the hot metal in the cooler parts of the gaseous envelope is not surprising; it is rather remarkable that not more of the characteristic flame spectra were observed. At the same time, the great affinity for oxygen of such metals as aluminium, magnesium, calcium, and barium might explain the appearance of the bands belonging to the oxides of these metals.

The one point which is difficult of explanation by any reasoning based on the assumption of a varying temperature is the absence of some of the characteristic strong lines, while others usually ascribed to the same temperature are present.

It seems probable that the environment of the point does pass through a very great range of temperature with each interruption of the current. There seems to be no reason for believing that the same is not true of the spark in air and the arc. In the spark in air the discontinuity of succeeding oscillations is quite complete, and the necessity for an explanation of the absence of lines ascribed to the lower temperatures seems as evident as in the case at hand. It seems probable that all three of these spectra, spark, arc, and Wehnelt, are composites, though this is not so evident in the usual methods of spectrum production.

In the Wehnelt, reversals were not observed in any case. This is remarkable, since Hale,[1] Hale and Kent,[2] Lockyer,[3] and others who have examined the spectra of the arc under liquids have shown that a very strong tendency toward reversal may exist under these circumstances. The mechanism of spectrum production in the two cases must be very different.

Lockyer gives, as the result of his investigations and as the basis of many deductions, four distinct stages of temperature, corresponding to the spectra of metals as they are produced in the laboratory. They are:

1. "The flame spectrum, consisting of a few lines and flutings

[1] ASTROPHYSICAL JOURNAL, **15**, 190, 1902.

[2] *Ibid.*, **17**, 155, 1903. [3] *Ibid.*, **15**, 190, 1902.

only, including several well-marked lines, some of them arranged in triplets.

2. "The arc spectrum, consisting of many lines.

3. "The spark spectrum, differing from the arc spectrum in the enhancement of some of the short lines and the reduced relative brightness of others.

4. "A spectrum consisting of a relatively very small number of lines which are enhanced in the spark. This latter spectrum is produced at a temperature which is that of the very center of the spark."

Lockyer has also made frequent use in his writings of a diagram showing a series of furnaces of increasing temperature, spectra being used to designate the temperature in each. The flame is taken as the lowest, the arc next, and then the spark, followed in application to astrophysical comparisons by the spectrum of a typical cooler star, than hotter ones, and so on. We have in the Wehnelt interrupter a "furnace" in which under constant experimental conditions a banded (compound) spectrum like that found for aluminium, and a pure line spectrum like that found for platinum, may be produced. The amount of current passing in the two cases is the same, the other factors of the experiment (composition of electrolyte, size of electrodes, etc.) remain constant, and there is every reason to believe that the maximum temperature reached is the same in the two cases. Any criterion of the temperature corresponding to either of these spectra would appear to be wanting unless they correspond to the *same* temperature. Nor does the fact of the absence of some of the strong lines of a metal appear to offer any measure, however qualitative, of the temperature, since other strong lines usually belonging to the same temperature are present.

It is certainly very easy to be led into reasoning in a circle in a case where much of our knowledge of temperatures has been deduced from observations on spectra, and much of our theory as to the correspondence of certain spectra with certain temperatures has been drawn ultimately from the same source.

Jefferson Physical Laboratory,
Harvard University.

THE SPECTRUM OF THE AURORA.

By E. C. C. Baly.

In the December number of the Astrophysical Journal[1] Professor Runge has drawn attention to Professor Paulsen's paper[2] upon the spectrum of the aurora, in which a comparison was drawn between this and the negative glow spectrum of a vacuum tube containing oxygen, a little nitrogen, and carbon monoxide. Professor Runge quite rightly, I think, points out that this comparison is misleading, as more striking results are obtained if we compare together the spectra of krypton and the aurora. In support of his contention Professor Runge gives a table of wave-lengths of the aurora lines together with some krypton lines, and also Paulsen's vacuum-tube lines; and he says that before any definite conclusions can be drawn more accurate measurements of the aurora lines are required. Recently Sykora[3] has published some measurements of these lines made from photographs taken at Spitzbergen in the winter of the year 1899. The figures he obtained are probably at least as accurate as any hitherto published, and a comparison of these with the krypton spectra gives an even more striking result than Professor Runge shows in his paper. In the table given below, lines are taken from both the krypton spectra; this is, I think, perfectly justifiable, for the following reason: Without doubt the auroral discharge takes place through very rarefied gas, especially if the atmospheric krypton be the main carrier of the electricity. It has long been known that when the ordinary discharge is passed through argon under reduced pressures, the red spectrum only is visible, unless the pressure be too low, when the blue spectrum and the red spectrum are simultaneously seen. The same is true of krypton, for when the pressure is greater than a certain small value, only the first krypton spectrum is

[1] Astrophysical Journal, **18**, 381, 1903.

[2] *Rapports présentés au congrès international de physique*, **3**, 438. Paris, 1900.

[3] *Acad. Sci. St. Pétersbourg, Mém.*, XI, **9**, 1, 1902.

visible; if now the pressure be reduced, a stage is soon reached at which the second, or jar and spark-gap spectrum makes its appearance, so that the two spectra are seen together. Such a condition might perfectly well obtain in the case of the aurora, and therefore lines are taken from both spectra in the following table.

Aurora		Krypton	
λ (Sykora)	Character	λ (Baly)	Intensity
5570	Strong	5570.50 (*ab*)	10
4710	Weak	4710.68 (*b*)	1
4429	Very weak	4431.85 (*b*)	4
4354	Very weak	4355.67 (*b*)	10
4276	Very strong	4274.15 (*ab*)	10
4190	Very weak	4185.29 (*b*)	2
4083	Very weak	4082.58 (*b*)	4
4057	Weak	4057.17 (*b*)	8
3995	Weak	3994.98 (*b*)	6
3912	Strong	3913.01 (*b*)	1
		3912.69 (*b*)	5
3804	Weak	3804.80 (*b*)	4
3754	Weak	3754.35 (*b*)	5
3707	Very weak	3708.23 (*b*)	1

The above measurements of the krypton lines are my own,[1] and the letters after the figures refer to the spectrum; *ab* means that the line is common to the two krypton spectra, and *b* that the line is only to be found in the second, or jar and spark-gap spectrum.

In addition to the above lines, Sykora says that there are many others which were too faint to measure. Paulsen gives in his list some other lines, not included in the above table, and these may be quoted here, as there are krypton lines sufficiently near to justify a comparison.

The last two bands or groups of lines clearly include the lines given by Sykora.

It may be pointed out that some of the krypton lines given above are among the weakest in the spectra of this gas; this is, however, no objection, as under certain conditions, when krypton is very much diluted by admixture of other gases, it is the

[1] *Phil. Trans.*, A, **202**, 183, 1903.

Aurora		Krypton	
λ in μμ (Paulsen)	Intensity	λ (Baly)	Intensity
463	10	4634.05 (*b*)	5
455	10	4556.77 (*b*)	4
449	10	4490.04 (*b*)	4
441.5–439.0	1	4408.10 (*b*)	2
		4386.69 (*b*)	4
436.0–430.5	1	4355.67 (*b*)	10
		4301.71 (*b*)	3
		4300.67 (*b*)	3
		4283.17 (*ab*)	4
428.5–425	10	4274.15 (*ab*)	10
		4268.97 (*b*)	3
		4268.72 (*b*)	2
		4259.60 (*b*)	3
		4254.98 (*b*)	3

weakest lines that are visible first. For example, in the spectrum of atmospheric argon only three of the krypton lines are visible, and these are some of the weakest in the krypton spectrum. Indeed, the line given in the second table at $\lambda = 4408.10$ is one of these, and this fact may even be taken as an argument in favor of its appearance in the aurora.

There hardly seems any doubt, from the above figures, of the very close connection between the auroral spectrum and the krypton spectra; further, it seems that it is the second krypton spectrum that is most concerned. This fact is, as stated above, only to be expected, if we consider the probably rarefied condition of this gas at the high altitudes at which the discharge takes place.

Spectroscopic Laboratory,
University College, London,
January 1904.

ON THE ANALYSIS OF BRIGHT SPECTRUM LINES.

By James Barnes.

It is well known that a change is produced in the wavelength and distribution of light in the lines of the spectrum of metallic vapors and gases when different external conditions are introduced. In most cases these changes were first observed and measured by means of the Rowland grating. Recently, however, these effects have become more readily observable through interference methods, in which the interference bands are produced with large differences in the paths of the rays.

Michelson,[1] by aid of his interferometer, resolved the important lines in the radiations of some vapors and gases rendered luminous in vacuum tubes, and he has studied these radiations in a magnetic field. With his echelon spectroscope he has investigated the same subjects. Fabry and Perot[2] with their interferometer have investigated the radiations from vapors in the electric arc and in vacuum tubes, and have applied their method for an exact determination of the wave-length of some of the lines in the spectrum of the iron arc and of the dark lines in the Sun's spectrum. Lummer[3] also by an interference method has studied the same radiations, particularly those from mercury, and has separated its prominent lines into many components.

When one compares the results of these investigations, the agreement is not very satisfactory. Not only do the number and intensity of the components differ, but the distances between the components do not agree.

The work presented in this paper was undertaken at the suggestion of Professor Ames. The objects of the work were: to

[1] *Phil. Mag.*, (5) **31**, 338, 1891; **34**, 280, 1892.

[2] *Ann. de Chim. et Phys.*, **12**, 459, 1897; **16**, 115 and 289, 1899. Astrophysical Journal, **9**, 87, 1899.

[3] *Verhandlungen d. D. Phys. Ges.*, **3**, 85, 1901. *Physikalische Zeitschrift*, (3) **8**, 172, 1902.

study interferometer methods; to obtain, if possible, more consistent results as to the constitution of the lines; and to determine the changes produced in the components under various conditions. Michelson remarks, in one of the papers cited:

> Still, in many cases, the range of visibility due to slight variations in the conditions shows that the behavior of each substance must be carefully studied under all possible circumstances of temperature, pressure, strength of current, size and shape of electrodes, diameter of vacuum tube, etc.

After experimenting a few months with both the Michelson and the Fabry and Perot interferometer, the author was fully convinced that the Fabry and Perot method possessed the advantage for the problems in view, since it shows directly the structure of a given radiation by the simple inspection of the system of fringes. Each fringe is, in fact, a true spectrum of the source, and the conditions are the same as those existing in the spectra obtained by the use of a grating having a small number of lines, but where the spectra employed are of a very high order. During the progress of the experiments the method proposed by Lummer appeared. While I have not been able to use this method exactly, I used, before I read his paper, one which is very similar to it. This method and results obtained will be described below.

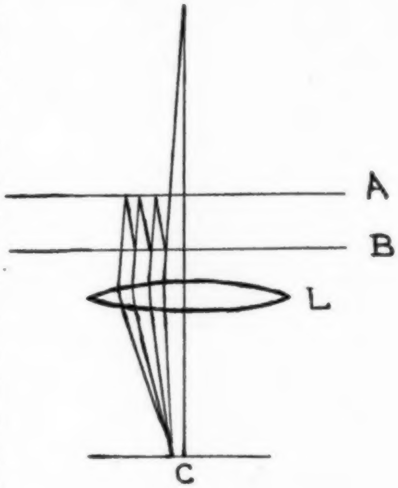


FIG. 1.

METHOD.

The method involved in this production of interference fringes will be first briefly considered, as it will assist toward a clear conception of the results.

Consider a ray of monochromatic light incident at an angle θ upon two glass plates, whose inside surfaces A and B (Fig. 1) are slightly silvered and separated from one another by a distance D. If the silvered surfaces are parallel, we have, on account of

the multiple reflections, a number of transmitted rays coming from the same source, whose differences of path increase in arithmetical progression. The differences of path with respect to the first are $2D \cos\theta$, $4D \cos\theta$, ... $2nD \cos\theta$. By means of a lens L these rays are brought to a focus in its focal plane, producing there an interference pattern, bright and dark bands, according as $2D \cos\theta$, $4D \cos\theta$, etc., are equal to an even or an odd number of half wave-lengths. If we have a symmetrical cone of rays incident upon the plates, the system of fringes obtained on a screen placed in the focal plane of the lens will be concentric circles, having as their center the point of intersection of the normal from the source upon the plates with the screen, C in the figure. The radii of these circles are equal to $f \tan\theta$, where f is the focal length of the lens L.

The intensity of the light at different points in this interference pattern was first worked out by Airy.[1] His formula is:

$$I = \frac{I_0(1-b^2)^2}{(1-b^2)^2 + 4b^2 \sin^2 \frac{(\pi\Delta)}{\lambda}},$$

where I_0 is the intensity of the incident light transmitted by the silvered surfaces, b the coefficient of reflection of the silvered surfaces, and Δ the difference of path of the rays. We see from this formula that for a given value of b, I will have a maximum when $\frac{2\Delta}{\lambda}$ is an even integer and a minimum when $\frac{2\Delta}{\lambda}$ is an odd integer. Hence the intensity of the bright fringes is I_0, while that of the dark fringes is

$$I_0\left(\frac{1-b^2}{1+b^2}\right)^2.$$

Fabry and Perot have calculated the values of I for different values of b, and have plotted curves showing the relation between I and Δ for these values of b. The greater the value of b, the steeper becomes the intensity curve, so that the interference pattern consists of bright fringes which are very narrow compared with the dark ones (see Plate XIX, Fig. 1). As we shall see later, the sharper and finer these bright bands are, the easier are the

[1] *Phil. Mag.*, (3) 2, 20, 1833.

radiations analyzed and the components measured. Thus, while on this account it is advantageous to have b very large, by increasing the thickness of the silver film, it must not be so large that I_0 the intensity of the light transmitted, is too small.

Let us now consider the light which is incident upon the plates not to be monochromatic, but to consist of two wave-lengths λ and $\lambda + d\lambda$; then the screen in the focal plane will be covered with two systems of concentric rings. At a definite separation of the plates let these two systems be in coincidence, then we have the relation

$$\frac{\Delta}{\lambda} = \frac{\Delta}{\lambda + d\lambda} + n \ ,$$

where n is any whole number, or

$$d\lambda = \frac{n\lambda^2}{\Delta - n\lambda} \, .$$

Since Δ is always large relative to $n\lambda$, we may write

$$d\lambda = \frac{n\lambda^2}{\Delta} = \frac{n\lambda^2}{2\,D\cos\theta} \, .$$

Thus by observing the first coincidence of the rings ($n = 1$) near the center of the system, where θ is so small that we may consider $\cos\theta = 1$, knowing the value of λ, and measuring D, the value of $d\lambda$ can be determined with a very high degree of accuracy. When $d\lambda$ is very small, it is not necessary for the determination of its value to separate the plates until the first coincidence occurs, but only till the separation of the rings is clearly visible. When the separation of the systems of rings is, say, one-quarter of the distance between consecutive rings of the same radiation, the equation becomes

$$d\lambda = \frac{\lambda^2}{8\,D} \, .$$

The resolving power of this method depends upon the distance between the plates, and also upon the angle of incidence of the light. The fringes near the center have thus the largest resolving power. It is also advantageous to make observations upon the central fringes, because their separation is the greatest.

This can be shown if we consider the length of the radii of the rings. With the center of the system a bright ring,

$$\Delta = 2D = m\lambda ,$$

where m is an integer; for the first bright fringe out from the center, the difference of path is

$$2D\cos\theta = (m-1)\lambda ;$$

hence,

$$\tan\theta = \frac{\sqrt{2m-1}}{m-1} ,$$

and the radius R_1 of the ring is given by the expression

$$R_1 = f\tan\theta = f\frac{\sqrt{2m-1}}{m-1} .$$

Similarly for the second bright fringe

$$2D\cos\theta = (m-2)\lambda ;$$

hence,

$$R_2 = f\frac{\sqrt{4m-4}}{m-2} ,$$

and so forth for R_3, R_4, etc.

The following table gives the values of R_1/f, R_2/f, etc., for different values of m:

m	R_1/f	R_2/f	R_3/f	R_4/f	R_5/f
1.........	∞				
2.........	1.732	∞			
3.........	1.118	2.828	∞		
4.........	0.882	1.732	3.873	∞	
100.........	0.143	0.203	0.251	0.292	0.329

From this table we see that when $m = 1$, *i. e.*, the difference of path is one wave-length, there is only one interference band, and its radius is infinite. Thus the field would be uniformly illuminated. When the difference of path is two wave-lengths, there are only two fringes, the first whose radius is $1.732\,f$, the radius of the second being infinite. For $m = 3$ there are three fringes. The entire system of bands could be observed only by means of infinite glass plates. We also see that as m gets large, which in practice is generally the case, the lower row in the

table shows us that the distance between the first and second rings is much larger than that between the second and third, and so on moving out in the system. Thus the separation of the fringes gradually diminishes as we go out from the center, and hence the advantage of making the observations on the central fringes. This is clearly shown by the figures on the plates, which are reproduced from photographs.

This interference method, besides being applied for the analysis of spectrum lines, can be used in the study of the changes in the wave-length of any radiation under the different conditions, as indicated above. Any small change will be shown by an increase or decrease in the diameters of these rings, and since very clear photographs can be taken, very accurate measurements of the changes produced can be obtained.

APPARATUS.

After experimenting some time with an instrument which seemed to be particularly sensitive to vibrations, even when every precaution was taken to eliminate extraneous disturbances, a new instrument was constructed. In the construction of this instrument the essential parts sought after were that the mountings for the plates should be rigid and placed on a massive base, so that the bands should be perfectly steady, and that the movable carriage carrying one plate should be capable of very slow uniform motion, always remaining parallel to its original position, enabling one to follow clearly the change from one band to another.

In working with a Michelson interferometer, as made by Gaertner & Co., the fringes obtained were very steady, even when the instrument rested on a table in the laboratory. I took this instrument, stripped it of its mirrors and plates, and, using the base, carriage, and screw, constructed the apparatus employed.

The apparatus consists of two plane glass plates 3.9cm by 2.5cm and about 0.6cm thick, each slightly prismatic in shape; the two faces making with one another an angle between 1″ and 2″. This prevents the interference bands formed in the plates themselves being superimposed upon those under observation. Both plates are rigidly mounted in brass frames. One frame can

be moved about a vertical axis and the other about a horizontal axis. For very small motions about these axes, so that the silvered surfaces may be made perfectly parallel, two glass tubes were bent into convenient shapes and clamped to the instrument. Their ends, resting against the frames, are covered with thin sheet rubber. To the other ends are attached long rubber tubes, and these are connected with a support. By carefully raising or lowering these tubes, which are filled with mercury, the pressure against the frames being therefore varied, very small rotations around either axis are obtained, and the surfaces thereby placed in perfect adjustment. Fabry and Perot employed this method, using water in their tubes instead of mercury. The carriage containing one of the frames rests upon steel ways, very accurately ground, and is connected by means of a small carriage, placed underneath, to a screw of 1 mm pitch. The force, being thus applied to the carriage in a direction parallel to the motion, produces no rocking, as is shown by the fact that the fringes always remained in adjustment during the motion.

To turn the screw, two handles are on the instrument, one for rapid and the other for slow motion. A turn of the first corresponds to one turn of the screw. The other is a tangent screw by which it is possible to give the carriage such a slow motion that the change from one fringe to the next can be easily followed. To both handles were attached graduated disks, enabling the distance between the plates to be accurately known.

The whole instrument weighed over 15 kg and was placed on a brick pier. The greater part of the observations were taken at night. With this instrument the fringes were always perfectly steady, and very long photographic exposures could be made without the least fear of obtaining a blurred image.

Since the radiations from all the sources studied consisted of many wave-lengths, it was necessary to employ some arrangement by which the wave-length under consideration could be separated from the others. The following (Fig. 2) was the plan first adopted. S is the source of light. The radiation undergoes an analysis by a Steinheil spectroscope consisting of two flint-glass prisms. The lens L brings the different wave-lengths

to a focus on a screen *I*, which contains a slit. Through this slit the wave-length considered is allowed to pass, and passing between the silvered plates forms the interference bands, which are observed by a telescope *T* or photographed.

The photographic apparatus consisted of a long light-proof box, which had a circular hole cut in one side. The eyepiece of the telescope being removed, the box was placed so that the opening fitted over the end of the telescope. The photographic plate, 13 × 3 cm, was in the focus of the objective and mounted so that it could be slid past the opening, and hence a number of exposures made upon one plate.

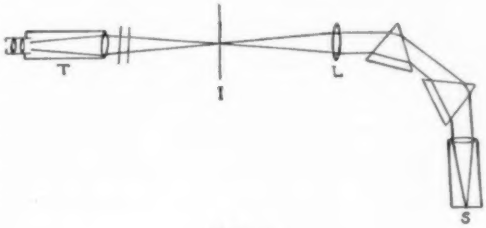


FIG. 2.

With the silvered plates illuminated in this way, with divergent light, the entire rings of the interference bands are observed in the focal plane of the objective as shown on Plate XIX, Fig. 1. The following method, however, was found to be better for the analysis of the radiations. The lens *L* was removed and the interferometer placed directly behind the prisms, so that the parallel light fell upon the silvered plates. With a broad slit in the spectroscope we have in the telescope, focused for infinity, broad lines corresponding to the lines in the spectrum. These lines are crossed with the interference bands produced by the plates. By this means the light has been concentrated into a few interference bands, and on this account many of the weaker components appear which cannot be seen with the light divergent as above. Fig. 2 (Plate XIX) shows this clearly. This photograph is of the bright-green mercury radiation, and shows three components when the interference plates are separated 8 mm.

This method possesses also another great advantage. Due to the number of lines in most spectra, we have in the field of the telescope at the same time a number of lines containing different kinds of interference bands depending upon the constitu-

tion of the radiation making up each line. This facilitates greatly the analysis of the radiations, and we see at once any change that may take place in one or all of the lines through any change of external conditions. The dispersion of the prisms and the magnification of the telescope were such that about half of the spectrum was visible at once. In Plate XIX, Figs. 3, 4, and 5 each show the interference bands due to the two yellow and green lines of mercury vapor taken at the same time with the plates separated at different distances. On account of the broad slit, the yellow lines passed through the interference plates together, and hence their interference bands are superimposed upon one another. The other lines in this region of the spectrum of mercury, being of less intensity, do not show in the photographs, which were exposed only long enough to get the clearest pictures of the lines considered. The dark-green line was quite visible to the eye after passing through the silvered plates. The curvature of the bands in the different lines is, of course, due to the amount of separation of the plates and to the angle of incidence with which the radiations are incident upon the interferometer plates.

For the determination of the scale-reading corresponding to the place where the silvered plates were in contact, a sodium flame or incandescent sodium vapor in a vacuum tube was employed. The slit of the spectroscope being wide, the two D lines were superimposed so that the two radiations together entered the interferometer. The plates were separated until the first coincidence happened, and the readings taken; the operation was repeated several times. Since the difference, $d\lambda$, between the sodium lines is known with accuracy from Rowland's tables, the distance D between the plates can be calculated from the above equation, and thus the zero point obtained. Readings were taken of the successive coincidences as the plates were separated, and in this manner the screw was calibrated. If a more accurate calibration is required, the two yellow lines of mercury can be used; since their distance apart is about three times that of the D lines, the coincidences occur three times more often in a given distance.

REMARKS ON INTERFERENCE BANDS.

Before considering the results, I will add some remarks concerning the general character of the interference bands obtained by this interference method.

When the silvered surfaces are not parallel, but are inclined to one another at a small angle, the fringes obtained are localized in the plates, and, as is well known, can be seen by the eye or with a lens focused on the plates. These fringes, however, can be obtained only when the separation of the plates is very small.

In order to procure clear interference bands with great differences of paths, it is necessary to have the surfaces rigidly parallel. The fringes in this case are seen by the eye, or by means of a telescope focused for infinity. One of the most important results of this work is that *the silvered faces of the plates must be perfectly parallel, and the telescope must be focused for infinity, to obtain correct results.* While this has been noted by former investigators, I wish strongly to emphasize the necessity for these adjustments; for if these two conditions are not fulfilled, all manner of anomalous results may be expected.

On Plate XIX are shown some photographs of some of the results obtained, if these conditions are not obeyed. Figs. 6–12 were all taken with the bright green line of incandescent mercury vapor in a vacuum tube. None of the photographs is magnified; the focal length of the objective used was about 15 cm.

The separation of the interference plates in Figs. 1, 6, and 7 was 3 mm. Fig. 1 is where the adjustments are perfect; Figs. 6 and 7 show the effect upon the bands when the interference plates are only a very small degree from being parallel, they being displaced from parallelism by merely raising one of the mercury adjusting tubes less than 1 cm. In Figs. 8 and 9 the plates are separated 0.5 mm, the plates in neither case being parallel. In Fig. 8 they have an angular separation of over 1′. These photographs also show the interference bands produced *in* the plates themselves superimposed upon the other.

As it is to advantage in the observations to obtain all the light possible, a broad source is always employed. The interfering rays from the different points of the source can produce a clear

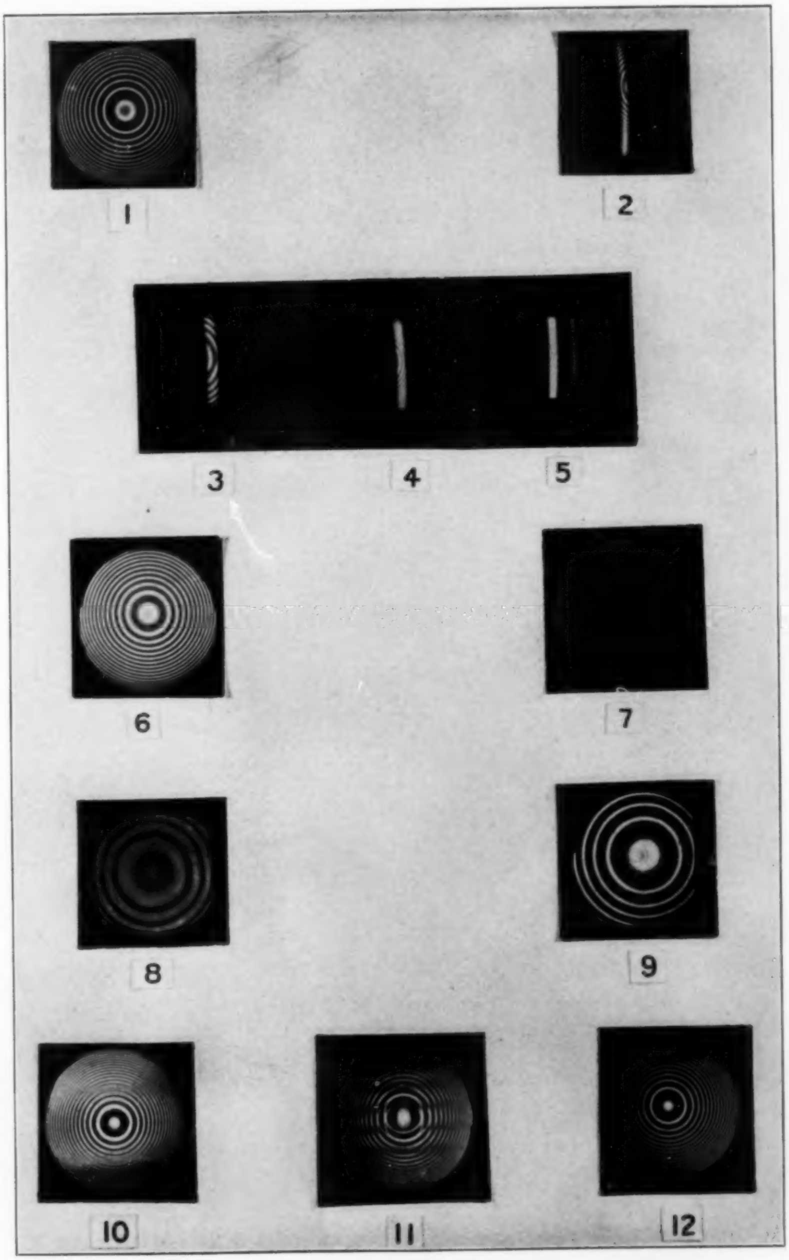
interference pattern only in the focal plane of the objective; in any other plane the bright interference bands will be wide and hazy. Figs. 10, 11, and 12 illustrate this point. The whole slit is covered, with the exception of two points separated 4 mm from one another in a horizontal direction. Fig. 10 shows the effect when the photographic plate is placed about 1 cm inside the focus of the objective; Fig. 11, when the plate is placed 2 cm beyond the focus; Fig. 12, when the plate is exactly in the focal plane; then the fringes produced by all points of the source are coincident, and give clear and sharp interference fringes. One can easily see that if the whole source were used instead of two points, the bands in Figs. 10 and 11 would be wide and hazy, so that if any of the bands due to the components of the radiation were present, they would probably be entirely obliterated.

To set the telescope at infinity is easy, but the adjustments necessary to obtain the silvered surfaces parallel are more or less difficult, and can be obtained only with practice. The plates are parallel when the fringes are sharp and the illumination equally distributed over the series of rings due to the components.

A REFLECTING INTERFEROMETER.

In the Fabry and Perot interferometer a large amount of light is lost, due to reflection from the surface of the silvering in contact with Plate A, Fig. 1, so that only a small percentage is transmitted. To eliminate this defect the plates were mounted according to the following Fig. 3. Plate A was heavily silvered and polished on its inside surface, and mounted on the carriage of the interferometer as described above. Plate B has its inside surface almost completely silvered, its reflecting power being about 0.9, and is mounted in the other frame. Light is incident upon Plate A, as shown in Fig. 3, and, due to multiple reflections between the silvered plates, we have transmitted a number of rays whose path-differences are in arithmetical progression, and the theory of the method is exactly as that sketched above. By this method the bright interference bands are much brighter than those obtained with the Fabry and Perot method, and hence the components are more readily seen. On account

PLATE XIX.



INTERFERENCE FRINGES UNDER VARIED CONDITIONS.

of the larger incident angle θ of the light upon the plates, the fringes observed are quite a distance from the center of the system, and are therefore close together, causing the necessary adjustments to make the plates parallel more difficult than with the method above, where the center of the system is used. Observations were made with these two methods, and the results agreed extremely well.

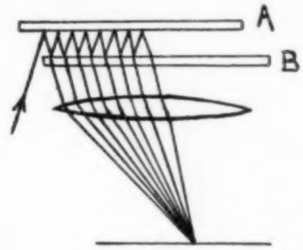


FIG. 3.

As mentioned in the introduction, a method proposed by Lummer appeared during these experiments. He employs only a long glass plate with parallel faces, and passes light into it by means of a prism at such an angle that it emerges at almost the critical angle. The method is very similar to the method above. In Lummer's method, however, since the thickness of a given glass plate is fixed, the positions of the components relative to one another cannot be determined; and if the faces of the plates are not perfectly parallel, many anomalous results, as those indicated above, may be obtained.

RESULTS.

On the basis of what has preceded, the following results have been obtained. A number of sources were employed — metallic vapors in vacuum tubes rendered luminous by the discharge from a large induction coil, metallic vapors in a Bunsen flame and in an electric arc, and lastly the electric spark between electrodes of the metals. This latter source was found to be very unsatisfactory. Of the many sources tried, the bright radiation from mercury vapor was the best for obtaining observations on the changes produced in the components by external changes in the conditions. We will thus first consider the results with this source. Great pains were always taken to have perfect adjustments, chiefly with respect to the focusing of the telescope and the parallelism of the interference plates, before any readings were taken.

The vacuum tube discharge was obtained in a Geissler tube

with mercury electrodes, of the form suggested by Runge and Paschen,[1] the capillary of which was placed directly in front of the slit of the spectroscope. The different tubes were connected to a Geryk pump and a pressure-gauge, enabling the pressure of the vapor through which the discharge passed to be quickly changed from a few millimeters to a fraction of a millimeter.

It is rather difficult to decide what is the most advantageous way to record results — whether to take what appears to be the center of gravity of the various components constituting the radiation as the position from which to measure wave-lengths, which is the usual way in the measurements of the lines obtained by means of the grating, or to consider the components of the greatest intensity as the standard and record the wave-lengths of the other components with reference to this. This latter method is the one employed by Michelson, and Fabry and Perot. Nevertheless, it is unsatisfactory, for I have found, even in some of the few radiations investigated, that there are two or more bright components whose intensities are equal. For want of a satisfactory standard, and also that the following results may be easily compared with those of the other investigators, their method, has, however, been followed. In the cases where the brightest components are of equal intensity, one of them has been selected for the standard. In what follows, the plus sign indicates that the component has a longer wave-length than the standard, the minus sign the reverse.

The following results were obtained after a long series of observations with a tube whose capillary was 0.5 mm in diameter and the vapor at a pressure of 1.5 mm. The bright green radiation whose wave-length is 5461 consists of six components. The

		Intensity
1	Standard component	1
2	-1.1×10^{-8} mm	$\frac{3}{4}$
3	-0.9×10^{-8}	$\frac{1}{4}$
4	-0.4×10^{-8}	1
5	$+0.1 \times 10^{-8}$	$\frac{1}{8}$
6	$+0.4 \times 10^{-8}$	$\frac{1}{4}$

[1] ASTROPHYSICAL JOURNAL **15**, 238, 1902.

two brightest having about equal intensities, the one having the longer wave-length will be considered the standard. The other components have the above differences in wave-length and in intensity relative to the one selected.

Thus there are three components on the side toward the shorter, and two toward the longer wave-lengths.

The violet line, $\lambda 4358$, is a triple having slight components on each side of the principal.

		Intensity
1	Standard component	1
2	-0.5×10^{-8} mm	$\frac{1}{4}$
3	$+0.4 \times 10^{-8}$	$\frac{1}{4}$

Both the yellow lines have numerous components, but they are of very slight intensity, so that concordant results were not obtainable.

When a small amount of air was allowed to enter the vacuum tube till the pressure was about 5 mm, the components of small intensity completely disappeared, the fringes due to the brighter components broadened, and their edges became less sharply defined, showing that the atomic vibrations were not so uniform and simple as before. The same effect was noticed with the radiation from a vacuum tube which had been used some time without any change of pressure. In the case where the pressure is changed through the introduction of air, the molecular collisions may be made more frequent, which would naturally interfere with the free vibrations of the atomic systems, and so produce a broadening of the bands and cause the less intense fringes to disappear. In the case of an old tube, when the pressure has not changed, there seems to be no other explanation for the observations than that the mercury vapor had become contaminated with gases driven off from the glass by the heat developed in the discharge.

Whether the atomic vibrations in a source are changed on account of the presence of molecules of foreign matter is an open question. Michelson[1] thinks that the presence of other

[1] *Phil. Mag.*, **34**, 280, 1892.

molecules does not have any appreciable effect except to diminish the visibility. In the case of mercury, when the pressure was high he obtained visibility curves quite different from those obtained when the pressure was low. When the mercury was placed in an atmosphere of hydrogen, the characteristics of the visibility curves were not changed. My results show, however, that when mercury is placed in the presence of air, both in the vacuum tube discharge and in the arc, which will be described later, the appearance of the interference bands is clearly changed, which can be due only to a change in the oscillations of the atomic systems. Schuster, in a lecture at the Royal Institution in 1881, drew from his results this conclusion: "Placing a molecule in an atmosphere of a different nature—without change of temperature—produces the same effect as would be observed in lowering the temperature." In a note to the ASTROPHYSICAL JOURNAL[1] he says: "Something similar seems to take place as regards pressure, for the sodium lines may be obtained wide c. narrow according as the atmosphere producing the pressure consists of sodium molecules only or of molecules of a different nature." The results here obtained seem to corroborate those of Schuster.

As being of some importance in this subject, I have introduced Figs. 14 and 15, Plate XX, showing the broad bands of the sodium lines, separated and superimposed, obtained with a sodium flame in air as the source. With sodium in a vacuum tube discharge, these bands are as sharp as those of the mercury fringes on Plate XIX. Fig. 13 was obtained with the green radiation from mercury in a tube which had been used a considerable time. The separation of the plates was 6 mm. Here not even one component is visible. A comparison of this photograph with that of Fabry and Perot reproduced in the ASTROPHYSICAL JOURNAL, May 1901, may interest the reader. This reproduction is of the fringes of the same line, with the same separation of plates, but shows the components. Figs. 13, 14, 15, Plate XX, have been magnified about four times. Fig. 16 has not been magnified, and shows how sharp the bands are when the plates are separated 1 cm.

[1] ASTROPHYSICAL JOURNAL, 3, 292, 1896.

Here also the components of the mercury green radiation are invisible.

With tubes containing capillaries whose diameters are greater than 2 mm the light obtained with an ordinary discharge is not sufficiently intense to show the finer components. The components that can be seen have their edges quite sharp, showing that the vibrations in these tubes are probably the same as in the tubes of smaller capillaries. The finer the capillary, the greater the electrical resistance to the discharge, and hence a rise in temperature, causing a brighter light. Temperature is an important factor, for by heating only the capillary of a tube where there is no liquid mercury present, and thus producing no noticeable change in the pressure in the vacuum tube, the kinetic energy of the atomic aggregations is increased such that many of the components of small intensity, invisible before, are now very readily seen.

The number and intensity of the components were the same whether the tube was placed "side on" or "end on;" that is, whether the discharge was perpendicular or parallel to the propagation of the light through the slit.

The introduction of capacity in parallel with the discharge circuit had an interesting effect. With three large Leyden jars, each a gallon jar, the fringes were broadened and the finer components disappeared. The effect appeared in every way analogous to that obtained when the pressure was increased.

The next step was to investigate the radiations from a mercury arc and to compare the results with those above. After many trials with different kinds of arcs, the following form (Fig. 4) was found the most satisfactory. The arc is between two mercury surfaces. *A* is an ordinary glass receiver of about 800 cu. cm capacity. Over the mouth *B* is sealed a piece of plate glass; through the rubber stopper *C* is run a glass tube which is connected to the Geryk pump. Through the stopper *D* is placed an iron tube *E* of diameter 13 mm. Along the axis of this is placed a porcelain tube *F* of diameter 8 mm. This porcelain tube is connected with a glass tube, which in turn is connected with a large rubber tube. The mercury fills the

space between the porcelain and iron tubes as well as the porcelain, glass, and rubber tubes attached. The electric poles are placed as shown in the figure. By raising the barometer column until a drop of mercury flows over into *E* the arc is started. Any further adjustments are easily carried out by raising or lowering the mercury column.

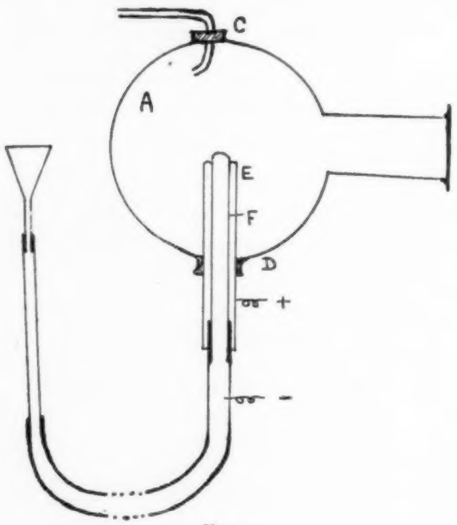


FIG. 4.

Since all the joints were made air-tight, the pressure could be varied by means of the pump. Within a few seconds after the arc is started the whole bulb of the receiver is covered with a layer of mercury thrown off from the arc. This does not penetrate into the neck, so that the glass at *B* is always clear, and the radiation from the arc passes through to the slit of the spectroscope without loss. The whole apparatus may be placed in a cold-water bath to keep the joints cool. This was found unnecessary with the apparatus used even when the arc was steadily run as long as ten minutes. Usually 110 volts were employed, the current was varied by means of a rheostat, and generally 4 amperes were used.

With the pressure under 5 mm the results were the same as those obtained with vacuum tubes, as given above. Above this pressure it was very difficult to obtain any components, and the bands were broad and hazy. This is probably due, as above, to pressure and the presence of a number of molecules of air.

The results obtained with the other metallic vapors and gases are briefly as follows:

Cadmium.—Small pieces of metallic cadmium were inclosed in a Geissler tube surrounded by an asbestos jacket. When heated with a Bunsen flame, the metal easily vaporized.

The red line, λ 6439, is nearly monochromatic. There is, however, a weak component toward the shorter wave-lengths:

		Intensity
1	Standard component	1
2	-0.1×10^{-8} mm	$\frac{1}{2}$

The green line, λ 5086, is composed of four components, the three weaker being on the side toward the larger wave-lengths:

		Intensity
1	Standard component	1
2	$+0.4 \times 10^{-8}$ mm	$\frac{1}{4}$
3	$+0.25 \times 10^{-8}$	$\frac{1}{4}$
4	$+0.1 \times 10^{-8}$	$\frac{1}{8}$

The blue line, λ 4800, has a component on each side of the principal:

		Intensity
1	Standard component	1
2	$+0.6 \times 10^{-8}$ mm	$\frac{1}{2}$
3	-0.4×10^{-8}	$\frac{1}{4}$

Thallium.—A piece of metallic thallium was placed on the end of a platinum wire and held in a Bunsen flame. The only bright radiation was that of the green line, λ 5439. A doubling of bands occurred when the plates were separated only a few millimeters. With a vacuum-tube radiation, another component was found with wave-length between the principal and first component:

		Intensity
1	Standard component	1
2	$+1.0 \times 10^{-8}$ mm	$\frac{3}{4}$
3	$+0.4 \times 10^{-8}$	$\frac{1}{4}$

Hydrogen.—By the kindness of Dr. Parsons, I used one of his tubes containing hydrogen which was specially pure, the

pressure being 1 mm. The red line easily breaks up into three components, one on each side of the brightest component:

		Intensity
1...........	Standard component	1
2...........	$+0.6 \times 10^{-8}$ mm	$\frac{1}{4}$
3...........	-0.2×10^{-8}	$\frac{1}{8}$

The green line is very complex. The components are so numerous that observations are very difficult.

The changes in the components due to changes in pressure, size of capillary, capacity in circuit, which were examined principally with the mercury radiations, were in some cases tried with the other radiations considered, and the results were in general the same. The above results, with respect to the relative wave-length and intensity of the components under the conditions specified, are collected in the following table, together with the results of Michelson, and Fabry and Perot, upon the same radiations obtained in vacuum tubes. Michelson's values are taken from the curves given in his paper. His method does not allow the determination as to whether the components have longer or shorter wave-lengths than the standard. The second list of values for the components of the mercury line, $\lambda = 5461$, obtained by Fabry and Perot are taken from a paper by Zeeman.[1]

Michelson		Fabry and Perot		Author	
Constitution and Separation ($\times 10^8$ mm)	Intensity	Constitution and Separation ($\times 10^8$ mm)	Intensity	Constitution and Separation ($\times 10^8$ mm)	Intensity
		Mercury, $\lambda = 5461$			
		I			
1. Stand. compon...	1	1. Stand. compon..	1	1. Stand. compon..	1
2. 1.2	$\frac{1}{10}$	2. +0.9	$\frac{1}{6}$	2. −1.1	$\frac{3}{4}$
3. 1.0	$\frac{1}{4}$	3. +0.1	$\frac{1}{8}$	3. −0.9	$\frac{1}{4}$
4. 0.7	$\frac{1}{10}$	II		4. −0.4	1
With two weak components near standard.		1. Stand. compon..	1	5. +0.1	$\frac{1}{8}$
		2. −2.2	$\frac{1}{2}$	6. +0.4	$\frac{1}{4}$
		3. −0.7	$\frac{1}{4}$		
		4. −0.5	$\frac{1}{8}$		
		5. +0.1	$\frac{1}{2}$		
		6. +0.8	$\frac{1}{3}$		
		7. +1.3	$\frac{1}{4}$		

[1] Astrophysical Journal, 15, 218, 1902.

Michelson		Fabry and Perot		Author	
Constitution and Separation ($\times 10^8$ mm)	Intensity	Constitution and Separation ($\times 10^8$ mm)	Intensity	Constitution and Separation ($\times 10^8$ mm)	Intensity
Mercury, $\lambda = 4358$					
1. Stand. compon... 2. 1.7 .... With two weak components near standard.	1 $\frac{1}{10}$			1. Stand. compon.. 2. −0.5 .... 3. +0.4	1 $\frac{1}{4}$ $\frac{1}{4}$
Cadmium, $\lambda = 6439$					
No components		No components		1. Stand. compon.. 2. −0.1	1 $\frac{1}{5}$
Cadmium, $\lambda = 5086$					
1. Stand. compon... 2. 0.2	1 $\frac{1}{5}$	1. Stand. compon.. 2. −0.3	1 $\frac{1}{8}$	1. Stand. compon.. 2. +0.4 .... 3. +0.25 .... 4. +0.1	1 $\frac{1}{4}$ $\frac{1}{4}$ $\frac{1}{8}$
Cadmium, $\lambda = 4800$					
1. Stand. compon... 2. 1.0	1 $\frac{1}{8}$	1. Stand. compon.. 2. +0.8 .... 3. −0.8	1 $\frac{1}{8}$ $\frac{1}{8}$	1. Stand. compon.. 2. +0.6 .... 3. −0.4	1 $\frac{1}{5}$ $\frac{1}{4}$
Thallium, $\lambda = 5439$					
1. Stand. compon... 2. 1.2 .... 3. 1.0 .... 4. 0.2	1 $\frac{1}{8}$ $\frac{1}{2}$ $\frac{1}{8}$	1. Stand. compon.. 2. +1.1 .... 3. +0.2	1 $\frac{1}{2}$ $\frac{1}{2}$	1. Stand. compon.. 2. +1.0 .... 3. +0.4	1 $\frac{3}{4}$ $\frac{1}{4}$
Hydrogen, $\lambda = 6563$					
1. Stand. compon... 2. 1.4	1 $\frac{3}{4}$			1. Stand. compon.. 2. +0.6 .... 3. +0.2	1 $\frac{1}{4}$ $\frac{1}{8}$

After the many long and tedious observations, together with the study and elimination of the errors which may enter into the results due to imperfect adjustments of the apparatus, the author

regrets that he is unable to present a more detailed account of the variations that occur in these component radiations, or satellites, as they have been called. The changes occur so suddenly on the least change of the surrounding conditions, and sometimes even when no changes apparent to the observer were introduced, that only qualitative results of a very general nature can be expressed.

During the observations upon the sharp interference fringes due to the mercury green radiation in the two cases, when the components were visible, as exemplified by the photograph given by Fabry and Perot, referred to above, and when, with the same separation of the silvered plates, the components were not present, as exemplified by Fig. 13, the question arose: Has the change in the conditions given birth to one or more satellites? The sharpness of the fringes in both cases; the unequal change in the intensity of the various components under variable conditions, as is shown when the capillary of a vacuum tube is heated; and the fact that the results given in the above table upon the distances between the components are in poor agreement, which is probably due to the different circumstances surrounding the radiation, all point to the possibility of the production of satellites. It must not be forgotten, however, that at the separation of the plates necessary to show the presence of the components, the interference bands are very close to one another, so that it is impossible in this method for an interference fringe due to the birth of a satellite to appear without overlapping some part of the interference fringes of the other components, and hence to produce a new distribution of light in the interference pattern which would naturally lead to different results.

The investigation of the variations in the wave-length and intensity of radiations separated by the grating on account of variation in pressure, electrical condition of the discharge, and the chemical nature of the dielectric surrounding the luminous substance, is at present a very fruitful field; for these changes in these widely separated lines lend themselves to measurement. It is hoped that a method will be found which will more readily show and give measurements of the many changes that occur in

radiations whose wave-lengths, and hence their frequencies, do not differ greatly, so that ultimately some knowledge may be obtained as to the mechanics of the systems of moving electrons constituting the atom whose periods differ by small amounts relative to those obtainable at present. A step in this direction has been made by Lummer. The reproductions in the *Ann. d. Phys.*, **10,** 473, 1903, show excellently the complicated structure of these bright radiations. The method proposed above, employing longer plates, is worthy of a fair trial.

My heartiest thanks are due to the professors and lecturers in physics in this University, especially to Professor Ames and Professor Wood, and also to my fellow-students, whose kind assistance in word and deed has greatly facilitated these experiments.

PHYSICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
February 1904.

DEFINITIVE ORBIT OF THE SPECTROSCOPIC BINARY *ι PEGASI*.[1]

By HEBER D. CURTIS.

THE spectroscopic binary *ι Pegasi* was discovered by Director Campbell and announced by him in the ASTROPHYSICAL JOURNAL for May 1899. It is of Type F, with fairly good lines. The forty-three plates upon which this orbit depends include all the plates of this star which have been taken with the Mills Spectrograph, with the exception of a few of poor focus or of insufficient exposure, which have been rejected. All the plates have been measured and reduced by the writer, except in the case of Plate 11, where the observed velocity is the mean of measures by Dr. H. M. Reese and the writer. Seven of the plates have been given half weight, generally because depending upon a smaller number of lines.

The following table gives the Greenwich Mean Times of the plates used in the discussion, the observed velocities, and the weights where they differ from unity:

No. of Plate	G. M. T.	Obs. Vel.	Residuals (Prelim. Orbit)	Weight
1..........	1897, Oct. 7.692	−50.0	−0.59	
2..........	1898, Aug. 19.822	−45.0	−1.18	
3..........	29.718	−38.3	−0.09	½
4..........	Sept. 28.703	−23.7	−0.55	
5..........	1899, June 11.998	−43.7	−0.01	
6..........	13.992	−43.2	−1.41	
7..........	July 2.939	−50.9	−1.25	
8..........	26.884	+12.1	−1.46	
9..........	Aug. 1.902	−41.8	−0.90	
10..........	Sept. 20.729	−10.2	+1.34	
11..........	21.684	−36.6	−1.14	
12..........	26.727	+26.3	−1.62	
13..........	27.684	+39.7	−2.45	
14..........	Oct. 3.712	−51.2	−1.40	½
15..........	9.696	+29.6	+2.88	½
16..........	17.699	+35.9	−1.97	
17..........	24.768	−42.5	−0.89	
18..........	25.724	−20.0	−1.45	

[1] Also to appear as a *Bulletin* of the Lick Observatory.

No. of Plate	G. M. T.	Obs. Vel.	Residuals (Prelim. Orbit)	Weight
19	31.673	−13.8	+0.16	
20	1902, July 20.895	−46.0	+0.85	½
21	Aug. 12.941	−23.1	−1.63	
22	17.926	+18.2	+2.96	½
23	18.949	−12.5	+0.32	
24	19.910	−36.5	+0.02	
25	25.798	+40.9	−0.76	
26	Sept. 14.876	+37.7	−0.25	
27	28.915	−15.5	+0.45	½
28	Oct. 8.888	− 6.8	+2.43	
29	Nov. 4.697	+34.2	+0.08	
30	1903, Jan. 3.603	− 1.3	−0.01	
31	4.620	+26.0	−0.78	
32	12.613	−35.7	−0.73	
33	14.608	+21.4	+0.21	
34	18.608	+ 3.8	+1.57	½
35	May 12.979	−44.4	+1.18	
36	18.008	+37.7	−0.46	
37	25.000	−42.9	−0.21	
38	27.958	+33.3	−0.72	
39	July 8.904	+44.2	+0.75	
40	12.982	−42.0	−0.70	
41	26.889	− 1.6	−0.94	
42	Aug. 10.947	+ 1.5	+1.33	
43	Dec. 1.677	−10.6	−0.03	
		$(pvv) =$	51.14	

The residuals in the preceding table were found from a preliminary orbit, using the formulæ and notation of Lehmann-Filhés (*A. N.*, **136**, 17, 1894). This orbit is as follows:

PRELIMINARY ELEMENTS.

Velocity of system $= -3.91$ km

$T = 1899$, June 15.515

$=$ Julian Day 2414821.515

$e = 0.0205$

$\omega = 272^\circ.732$

$\log \mu = 9.78864$

$\log \kappa = 1.67574$

Period $= 10^d.2132$

From these elements the differential coefficients were computed and the equations of condition formed, introducing a sixth unknown with the coefficient unity for the change in the assumed velocity of the system. After weighting, these coefficients were

rendered homogeneous by the introduction of the following factors:

$$x = \delta V$$
$$y = 30.34\ \delta T$$
$$z = 73420\ \delta\mu$$
$$u = \delta\kappa$$
$$v = 48.30\ \delta\omega$$
$$w = 47.60\ \delta e$$
$$\log \text{unit error} = 0.3892$$

From this process were derived the following equations of condition (coefficients natural numbers):

Number	*a*	*b*	*c*	*d*	*e*	*f*	*n*
1	+1.000 *x*	+0.270 *y*	+0.112 *z*	−0.958 *u*	−0.259 *v*	+0.581 *w*	−0.241=0
2	+1.000	+0.513	+0.103	−0.836	−0.516	+0.924	−0.482
3	+0.707	+0.458	+0.089	−0.508	−0.468	+0.699	−0.024
4	+1.000	+0.847	+0.148	−0.401	−0.878	+0.695	−0.225
5	+1.000	+0.516	+0.001	−0.834	−0.519	+0.927	−0.004
6	+1.000	−0.590	−0.001	−0.799	+0.609	−0.947	−0.575
7	+1.000	+0.254	−0.003	−0.962	−0.243	+0.553	−0.510
8	+1.000	−0.929	+0.026	+0.370	+0.932	+0.655	−0.596
9	+1.000	+0.588	−0.019	−0.777	−0.596	+0.976	−0.367
10	+1.000	+0.912	−0.060	−0.155	−0.949	+0.259	+0.547
11	+1.000	+0.699	−0.046	−0.660	−0.716	+0.974	−0.465
12	+1.000	−0.734	+0.051	+0.674	+0.746	+0.993	−0.661
13	+1.000	−0.223	+0.016	+0.975	+0.245	+0.488	−1.000
14	+0.707	−0.171	+0.013	−0.684	+0.188	−0.312	−0.404
15	+0.707	+0.502	−0.039	+0.460	−0.513	−0.695	+0.833
16	+1.000	−0.459	+0.038	+0.885	+0.479	+0.853	−0.804
17	+1.000	−0.593	+0.052	−0.798	+0.611	−0.950	−0.363
18	+1.000	−0.949	+0.084	−0.312	+0.952	−0.635	−0.592
19	+1.000	+0.903	−0.084	−0.208	−0.940	+0.359	+0.065
20	+0.707	+0.286	−0.217	−0.638	−0.283	+0.563	+0.245
21	+1.000	−0.925	+0.717	−0.373	+0.930	−0.732	−0.665
22	+0.707	+0.598	−0.465	+0.289	−0.619	−0.541	+0.853
23	+1.000	+0.907	−0.706	−0.182	−0.945	+0.311	+0.131
24	+1.000	+0.680	−0.530	−0.683	−0.695	+0.982	+0.008
25	+1.000	−0.258	+0.202	+0.966	+0.280	+0.551	−0.310
26	+1.000	−0.458	+0.365	+0.885	+0.478	+0.852	−0.102
27	+0.707	+0.632	−0.510	−0.175	−0.658	+0.307	+0.131
28	+1.000	+0.917	−0.745	−0.108	−0.955	+0.168	+0.992
29	+1.000	−0.591	+0.490	+0.803	+0.606	+0.973	+0.032
30	+1.000	−1.000	+0.871	+0.057	+1.000	+0.064	−0.004
31	+1.000	−0.756	+0.659	+0.649	+0.767	+0.982	−0.318
32	+1.000	−0.746	+0.654	−0.657	+0.759	−1.000	−0.298
33	+1.000	−0.843	+0.741	+0.534	+0.851	+0.884	+0.086
34	+0.707	+0.647	−0.570	+0.095	−0.674	−0.216	+0.453
35	+1.000	+0.453	−0.434	−0.876	−0.452	+0.861	+0.482
36	+1.000	−0.450	+0.432	+0.889	+0.470	+0.842	−0.188
37	+1.000	−0.563	+0.544	−0.819	+0.582	−0.923	−0.086
38	+1.000	−0.591	+0.572	+0.802	+0.607	+0.974	−0.295
39	+1.000	+0.038	−0.038	+1.000	−0.019	−0.031	+0.306
40	+1.000	+0.580	−0.579	−0.784	−0.588	+0.972	−0.286
41	+1.000	−0.999	+1.007	+0.071	+0.999	+0.092	−0.383
42	+1.000	+0.919	−0.936	+0.090	−0.957	−0.221	+0.543
43	+1.000	+0.914	−1.000	−0.136	−0.952	+0.223	−0.012

From these were derived the following normal equations:

x	y	z	u	v	w	n	s
+39.499	+ 0.340	+ 1.503	− 3.489	− 0.416	+13.391	−5.163	+45.664
	+19.412	−10.661	− 6.474	−19.863	+ 3.751	+6.954	− 6.540
		+ 9.588	+ 2.790	+10.917	+ 0.114	−4.071	+10.179
			+18.341	+ 6.615	+ 2.435	+0.659	+20.876
				+20.332	− 3.783	−7.164	+ 6.637
					+21.994	−3.338	+34.563
						+9.102	− 3.025

The solution of these equations gives for the values of the unknown quantities and their probable errors:

$\delta V = -0.12$ km	± 0.11 km
$\delta T = -0.349$ days	± 0.219
$\delta\mu = +0.0000050$	± 0.0000042
$\delta\kappa = +0.564$	± 0.152
$\delta\omega = -0.242$	± 0.0304 radians
$= -13^\circ.880$	$\pm 1^\circ.740$
$\delta e = -0.0119$	± 0.0032

giving for the corrected elements:

$V = -4.03$	± 0.11 km
$T =$ 1899, June 15.166	± 0.219 days
$e = 0.0086$	± 0.0032
$\omega = 258^\circ.852$	$\pm 1^\circ.740$
$\log \mu = 9.7890216$	± 0.0000029
$\mu = 35^\circ.2488$	$\pm 0^\circ.0002$
$U = 10.21312$	± 0.00006 days
$\log \kappa = 1.68088$	± 0.00014

The sum of the squares of the weighted residuals has been reduced by this solution from 51.14 to 26.28. On computing an ephemeris from these changed elements, however, and comparing these changes in the residuals with those secured by substitution in the equations of condition, it was found that the differences were considerably larger than could be attributed to the ordinary errors of logarithmic computation, showing that the effect of terms of the second order in the differential coefficients was of appreciable magnitude. A second solution was therefore necessary. Using the ephemeris based upon the second set of elements, and recomputing the differential coefficients, the following set of equations was derived:

Number	*a*	*b*	*c*	*d*	*e*	*f*	*n*
1	+1.000*x*	+0.285*y*	+0.112*z*	−0.959*u*	−0.279*v*	+0.382*w*	−0.013=0
2	+1.000	+0.540	+0.103	−0.835	−0.540	+0.824	−0.388
3	+0.707	+0.485	+0.090	−0.504	−0.488	+0.688	−0.018
4	+1.000	+0.896	+0.148	−0.385	−0.908	+0.825	−0.549
5	+1.000	+0.543	+0.001	−0.833	−0.543	+0.828	+0.152
6	+1.000	−0.597	±0.000	−0.802	+0.603	−0.995	−0.326
7	+1.000	+0.265	−0.003	−0.964	−0.259	+0.343	−0.286
8	+1.000	−0.939	+0.025	+0.338	+0.942	+0.777	−0.040
9	+1.000	+0.619	−0.019	−0.775	−0.621	+0.917	−0.295
10	+1.000	+0.960	−0.006	−0.132	−0.975	+0.437	+0.098
11	+1.000	+0.738	−0.046	−0.654	−0.744	+0.993	−0.522
12	+1.000	−0.762	+0.050	+0.641	+0.768	+1.000	−0.179
13	+1.000	−0.272	+0.018	+0.959	+0.283	+0.357	−1.000
14	+0.707	−0.176	+0.012	−0.686	+0.183	−0.457	−0.210
15	+0.707	+0.501	−0.037	+0.482	−0.507	−0.679	+0.317
16	+1.000	−0.503	+0.040	+0.859	+0.513	+0.765	−0.554
17	+1.000	−0.600	+0.050	−0.800	+0.606	−0.996	−0.062
18	+1.000	−0.948	+0.080	−0.323	+0.948	−0.444	−0.192
19	+1.000	+0.952	−0.084	−0.187	−0.967	+0.533	−0.380
20	+0.707	+0.296	−0.214	−0.640	−0.294	+0.447	+0.460
21	+1.000	−0.927	+0.683	−0.378	+0.927	−0.547	−0.388
22	+0.707	+0.615	−0.455	+0.309	−0.625	−0.461	+0.402
23	+1.000	+0.955	−0.707	−0.165	−0.970	+0.496	−0.228
24	+1.000	+0.714	−0.529	−0.681	−0.719	+0.987	+0.098
25	+1.000	−0.302	+0.225	+0.950	+0.312	+0.414	−0.281
26	+1.000	−0.497	+0.376	+0.863	+0.507	+0.756	+0.156
27	+0.707	+0.666	−0.511	−0.165	−0.677	+0.431	−0.080
28	+1.000	+0.964	−0.745	−0.090	−0.980	+0.359	+0.661
29	+1.000	−0.622	+0.491	+0.777	+0.631	+0.917	+0.406
30	+1.000	−1.000	+0.828	+0.036	+1.000	+0.268	+0.451
31	+1.000	−0.778	+0.645	+0.621	+0.785	+1.000	+0.112
32	+1.000	−0.754	+0.629	−0.657	+0.758	−0.944	−0.058
33	+1.000	−0.859	+0.717	+0.506	+0.863	+0.953	+0.536
34	+0.707	+0.675	−0.566	+0.112	−0.687	−0.890	+0.080
35	+1.000	+0.470	−0.428	−0.879	−0.468	+0.719	+0.790
36	+1.000	−0.488	+0.446	+0.868	+0.498	+0.741	+0.045
37	+1.000	−0.576	+0.529	−0.818	+0.582	−0.989	+0.165
38	+1.000	−0.623	+0.573	+0.777	+0.631	+0.917	+0.036
39	+1.000	−0.004	+0.003	+0.998	+0.012	−0.186	+0.134
40	+1.000	+0.605	−0.575	−0.787	−0.607	+0.905	−0.112
41	+1.000	−1.000	+0.958	+0.050	+1.000	+0.295	+0.018
42	+1.000	+0.961	−0.930	+0.113	−0.955	−0.035	+0.045
43	+1.000	+0.961	−1.000	−0.120	−0.977	+0.416	−0.371

As in the first solution, these equations have been made homogeneous by the factors

$$x=\delta V$$
$$y=29.98\delta T$$
$$z=76350\delta\mu$$
$$u=\delta\kappa$$
$$v=48.33\delta\omega$$
$$w=48.11\delta e$$

log unit error=0.3502

The following normal equations result from the equations of condition given above:

x	y	z	u	v	w	n	s
+39.499	+ 0.541	+ 1.470	− 3.640	− 0.531	+13.337	− 1.648	+49.027
	+20.822	−10.772	− 6.618	−20.995	+ 3.711	− 0.343	−13.653
		+ 9.262	+ 2.665	+10.859	+ 0.313	+ 0.110	+13.906
			+17.953	+ 6.683	+ 2.279	+ 0.439	+19.760
				+21.172	− 3.711	+ 0.337	+13.812
					+21.743	− 0.635	+37.036
						+ 5.339	+ 3.598

VALUES OF UNKNOWNS — SECOND SOLUTION.

$\delta V = -0.09$ ± 0.11 km
$\delta T = -0.200$ ± 0.352 days
$\delta\mu = +0.00000007$ ± 0.00000407
$\delta\kappa = +0.0327$ ± 0.1523
$\delta\omega = -0.1230$ ± 0.0240 radians
$\delta e = -0.00008$ ± 0.0040

FINAL ELEMENTS

$V = -4.12$ ± 0.11 km
$T = 1899$, June 14.966 ± 0.352 days
$=$ J. D. 2414820.966
$e = 0.0085$ ± 0.0040
$\omega = 251^\circ.807$ $\pm 1^\circ.373$
$\log \kappa = 1.68117$ ± 0.00014
$\log \mu = 9.7890216$ ± 0.0000029
$\mu = 35^\circ.2488$ $\pm 0^\circ.0002$
Period $= 10.21312$ ± 0.00006 days
$a \sin i = 6{,}740{,}000$ km

This solution is satisfactory, as may be seen from the accompanying table, in which are given the residuals from the two solutions and the comparisons of these residuals with the values found by substitution in the equations of condition.

No.	First Solution		Second Solution		Weight
	Resid.	Eph.−Eq.	Resid.	Eph.−Eq.	
1	−0.03	+0.10	+0.11	+0.01	
2	−0.87	−0.16	−0.71	+0.04	
3	−0.05	+0.03	+0.09	+0.02	½
4	−1.23	−0.07	−1.15	−0.01	
5	+0.34	−0.16	+0.49	+0.02	
6	−0.73	−0.22	−0.62	+0.01	
7	−0.64	−0.23	−0.47	+0.02	
8	−0.09	+0.04	−0.04	−0.02	
9	−0.66	−0.13	−0.52	+0.03	

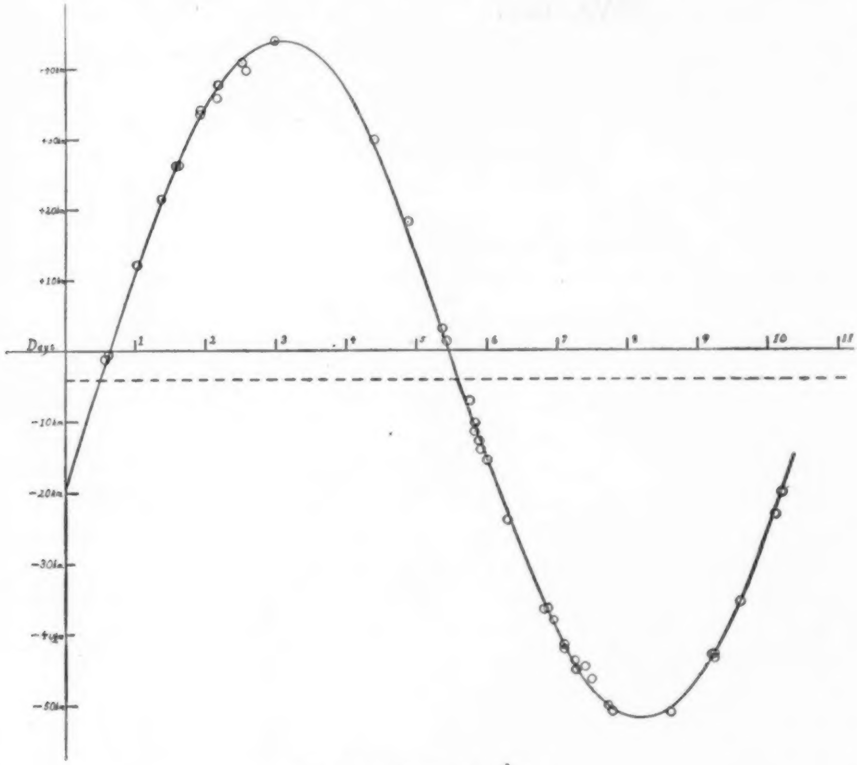
No.	First Solution		Second Solution		Weight
	Resid.	Eph. − Eq.	Resid.	Eph. − Eq.	
10	+0.22	−0.06	+0.28	−0.02	
11	−1.17	−0.10	−1.04	+0.02	
12	−0.40	+0.01	−0.33	−0.01	
13	−2.24	−0.14	−2.14	0.00	
14	−0.67	−0.15	−0.51	+0.03	
15	+1.00	−0.12	+1.05	−0.02	½
16	−1.24	−0.10	−1.13	+0.02	½
17	−0.14	−0.14	−0.03	+0.01	
18	−0.43	+0.02	−0.38	−0.01	
19	−0.85	−0.04	−0.78	−0.01	
20	+1.45	−0.13	+1.62	+0.04	½
21	−0.87	+0.02	−0.82	−0.02	
22	+1.27	−0.06	+1.32	−0.02	½
23	−0.51	+0.05	−0.45	−0.01	
24	+0.22	−0.13	+0.35	+0.01	
25	−0.63	−0.24	−0.52	+0.01	
26	+0.35	−0.12	+0.47	+0.01	
27	−0.25	−0.04	−0.19	−0.02	½
28	+1.48	+0.12	+1.54	−0.02	
29	+0.91	+0.11	+1.00	−0.02	
30	+1.01	−0.01	+1.03	+0.01	
31	+0.25	−0.06	+0.32	−0.03	
32	−0.13	−0.17	−0.04	0.00	
33	+1.20	−0.03	+1.27	−0.02	
34	+0.25	−0.18	+0.29	+0.01	½
35	+1.77	−0.11	+1.94	−0.02	
36	+0.10	−0.11	+0.21	+0.05	
37	+0.37	−0.12	+0.48	+0.02	
38	+0.08	−0.06	+0.17	0.00	
39	+0.30	−0.18	+0.41	+0.01	
40	−0.25	−0.13	+0.10	+0.04	
41	+0.04	+0.14	+0.08	−0.02	
42	+0.10	−0.05	+0.14	0.00	
43	−0.83	−0.04	−0.78	−0.03	

The probable error of a single plate derived from this solution is ±0.56km. The relatively large probable errors in the values of T and ω arise from the fact that the orbit is so nearly a circle, the eccentricity being only +0.0085. On the other hand, inasmuch as the observations cover two hundred and nineteen complete revolutions of the star, the period is determined with considerable accuracy.

The accompanying diagram shows the curve of the final orbit and the observed places as derived from the plates, which are represented by small circles. The largest residual is −2.14 km;

the range of velocity is from $+43.7$ to -52.1 km per second. The dotted line represents the velocity of the center of mass of the system.

There is no evidence on any of the plates of a second spec-



Velocity-Curve of ι *Pegasi.*

trum from which to make an estimate of the relative velocities in the system. Dr. R. G. Aitken states that he examined ι *Pegasi* in 1901 with the 36-inch refractor, but found no evidence of duplicity.

LICK OBSERVATORY,
March 4, 1904.

MINOR CONTRIBUTIONS AND NOTES.

VARIABILITY OF *IRIS* (7).[1]

A SERIES of measurements of the light of the planet *Iris* (7) has been made by Professor Wendell with the polarizing photometer, with sliding achromatic prisms, attached to the fifteen-inch equatorial telescope of the Harvard College Observatory. A variation like that of the planet *Eros* has been established, having a period of about $0^{d}.259 = 6^{h}\ 13^{m}$. The range is only two or three tenths of a magnitude, and the variation would be uncertain but for the very small accidental errors which occur in observations made in this way. See *Circulars* Nos. 23, 25, 30, and 41.

The results of the measures made by Professor Wendell are given in Table I. The Julian Day and fraction following Greenwich Mean Noon, omitting the three left-hand figures, 241, is given in the first column. The designation of the comparison star is given in the second column. The observed difference in magnitude between *Iris* and the comparison star is given in the third column, a positive sign indicating that the star was brighter than *Iris*. The fourth column gives the phase computed by the formula $2{,}416{,}470^{d}.000 + 0^{d}.259\ E$. The fifth column gives the amount that *Iris* is fainter than its assumed maximum magnitude. This quantity was found by plotting the times and observed differences in magnitude on each night, and by inspection assuming the maximum magnitude. The latter was then subtracted from the observed magnitude, and a curve constructed from these differences and the corresponding phases. Owing to errors in the assumed maximum magnitudes, the points on some nights were above and on others below the curve. The mean value of the deviations from the curve for each night was therefore subtracted from these differences and gives the quantity contained in the fifth column. Negative signs are indicated by *italics*. This process was necessary, since different stars was used on different nights, and we had no means of knowing their true magnitudes. The sixth column gives the residual found by subtracting the magnitude as given by a smooth curve from that contained in the fifth column. The average value of these forty-six residuals is only ± 0.022.

[1] *Harvard College Observatory Circular* No. 70.

TABLE I.

Observations of *Iris* (7).

J. D.	*B. D.*	Diff.	Phase	M.	O.–C.
6475.606	+18°1576	–0.79	0.167	0.22	0.03
.612	" "	–0.86	0.173	0.15	*0.02*
.658	" "	–1.01	0.219	0.00	*0.01*
.665	" "	–1.02	0.226	*0.01*	*0.02*
6477.645	+18 1553	–0.96	0.134	0.06	*0.02*
.651	" "	–0.90	0.140	0.12	0.02
.662	" "	–0.86	0.151	0.16	0.00
6479.603	+18 1538	+0.12	0.020	0.21	0.02
.611	" "	+0.11	0.028	0.20	*0.01*
.656	" "	–0.02	0.073	0.07	0.04
.664	" "	–0.07	0.081	0.02	0.00
6480.552	" "	–0.08	0.192	0.05	*0.02*
.558	" "	–0.13	0.198	0.00	*0.04*
.586	" "	–0.07	0.226	0.06	0.05
.612	" "	–0.07	0.252	0.06	*0.01*
.621	" "	–0.04	0.002	0.09	*0.03*
6485.565	+18 1496	–1.66	0.025	0.25	0.04
.570	" "	–1.68	0.030	0.23	0.02
.601	" "	–1.83	0.061	0.08	0.00
.606	" "	–1.91	0.066	0.00	*0.04*
.624	" "	–1.88	0.084	0.03	0.01
.631	" "	–1.90	0.091	0.01	*0.01*
.651	" "	–1.86	0.111	0.05	0.00
.660	" "	–1.83	0.120	0.08	0.02
6487.540	+18 1495	–1.68	0.187	0.10	0.00
.546	" "	–1.72	0.193	0.06	0.00
.568	" "	–1.76	0.215	0.02	0.01
.576	" "	–1.76	0.223	0.02	0.01
.599	" "	–1.73	0.246	0.05	0.00
.606	" "	–1.75	0.253	0.03	*0.04*
.627	" "	–1.64	0.015	0.14	*0.04*
.636	" "	–1.59	0.024	0.19	*0.02*
.656	" "	–1.68	0.044	0.10	*0.03*
.664	" "	–1.71	0.052	0.07	*0.01*
6495.567	+18 1419	–1.00	0.185	....	....
.574	" "	–1.02	0.192	....	....
6498.543	+18 1391	–1.99	0.053	0.08	0.00
.551	" "	–2.04	0.061	0.03	*0.02*
6499.524	" "	–1.82	0.257	0.21	0.10
.530	" "	–1.82	0.004	0.21	0.07
.546	" "	–1.80	0.020	0.23	0.03
.552	" "	–1.82	0.026	0.21	0.00
.578	" "	–1.96	0.052	0.07	*0.01*
.585	" "	–1.97	0.059	0.06	0.00
.603	" "	–2.01	0.077	0.02	0.00
.610	" "	–2.08	0.084	*0.05*	*0.07*
.630	" "	–2.03	0.104	0.00	*0.03*
.660	" "	–1.96	0.134	0.07	*0.03*

The co-ordinates of the light-curve are given in Table II. The phases are given in the first and third columns; the corresponding

magnitudes, in the second and fourth columns. The differences found by subtracting the numbers in the fourth column from those in the second are given in the fifth column. It will be seen, therefore, that there are two maxima and two minima, which are so nearly equal that it is as yet impossible to say whether the differences are real or due to small systematic errors. In the latter case, the period should be divided by two, and become $0^d.1295 = 3^h\ 6^m$.

It will be seen that the variation closely resembles that of *Eros*, and that the conditions discussed in *Circular* No. 58 apply to *Iris* also. The latter asteroid is bright enough to be readily observed during a large part of the time, but unfortunately the change of light is now so small that it can be determined only by observations in which the accidental errors are extremely small. In fact, the observations of *Iris* made at Potsdam in 1884 (*Publicationen*, **8**, 294) fail to show this variation, either because the range was then too small, the period was then different, or the errors of observation rendered the variation imperceptible. The average of the residuals on the twenty-six nights of observation was ± 0.073, or about the same as that for the other asteroids. A change in the period seems improbable.

TABLE II.

Light-Curve.

Ph.	M.	Ph.	M.	Diff.	Ph.	M.	Ph.	M.	Diff.
0.00	0.12	0.13	0.09	0.03	0.07	0.03	0.20	0.06	*0.03*
0.01	0.16	0.14	0.12	0.04	0.08	0.02	0.21	0.02	0.00
0.02	0.19	0.15	0.17	0.02	0.09	0.02	0.22	0.01	0.01
0.03	0.21	0.16	0.19	0.02	0.10	0.03	0.23	0.02	0.01
0.04	0.17	0.17	0.18	*0.01*	0.11	0.04	0.24	0.03	0.01
0.05	0.10	0.18	0.14	*0.04*	0.12	0.06	0.25	0.03	0.03
0.06	0.05	0.19	0.09	*0.04*					

The observations contained in Table III was made on January 25, 1904, after the above discussion was completed. *Iris* was compared with $+17^\circ.1404$, and the Julian Day and fraction, difference in magnitude, and phase are given in the successive columns. It will be seen, by plotting these observations, that they fall almost exactly upon a smooth curve, and that the phase of maximum, $0^d.085$, agrees very nearly with that derived from the previous observations. A change, however, appears to have taken place in the range, which now exceeds three-tenths of a magnitude, or an increase of about one half in a few days. This change is confirmed by the last ten residuals in the last

column of Table I, which indicate that the increase in range occurred between J. D. 6487 and J. D. 6499. The change in the range of *Eros* in the spring of 1901 was also much more rapid than might have been expected from geometrical considerations. The range on March 12, 1901, was found to be about 1.0; on April 12, 1901, 0.4; and on May 6 and 7, 1901, 0.0, magnitudes.

Evidently, this object should be watched carefully. It is now favorably situated, as it is approaching its second stationary point, and is of about the eighth magnitude. *Iris* can be conveniently compared photometrically with the stars $+17^\circ.1339$, $+17^\circ.1355$, $+17^\circ.1364$, and $+17^\circ.1391$, during the next few weeks, and it is hoped that observers elsewhere will connect their observations with these stars and with the comparison stars used in Tables I and III, so that all may be reduced to one system. Measures of the absolute magnitudes of these stars will be undertaken here. It will be noticed that observations on each night should extend over at least three hours. In that case, a maximum and minimum will always be included, so that the absolute magnitudes of the comparison stars will be of less importance.

TABLE III.

Later Observations.

J. D.	Diff.	Ph.	J. D.	Diff.	Ph.
6505.539	−0.52	0.056	6505.610	−0.44	0.127
.546	−0.56	0.063	.619	−0.37	0.136
.562	−0.59	0.079	.636	−0.28	0.153
.569	−0.60	0.086	.645	−0.34	0.162
.585	−0.58	0.102	.656	−0.38	0.173
.592	−0.56	0.109	.662	−0.46	0.179

EDWARD C. PICKERING.

JANUARY 1904.

PUBLICATIONS OF THE YERKES OBSERVATORY.

THE following papers, recently issued by the University of Chicago Press, as THE DECENNIAL PUBLICATIONS of the University of Chicago, are being reprinted in Volume II of the PUBLICATIONS OF THE YERKES OBSERVATORY, and will soon be distributed to correspondents:

I. MEASURES OF DOUBLE STARS WITH THE FORTY-INCH REFRACTOR OF THE YERKES OBSERVATORY IN 1900 AND 1901. *By Sherburne Wesley Burnham.*

II. MICROMETRICAL OBSERVATIONS OF *EROS* MADE WITH THE FORTY-INCH REFRACTOR OF THE YERKES OBSERVATORY DURING THE OPPOSITION OF 1900–1901. *By Edward Emerson Barnard.*

III. ON CERTAIN RIGOROUS METHODS OF TREATING PROBLEMS IN CELESTIAL MECHANICS. *By Forest Ray Moulton.*

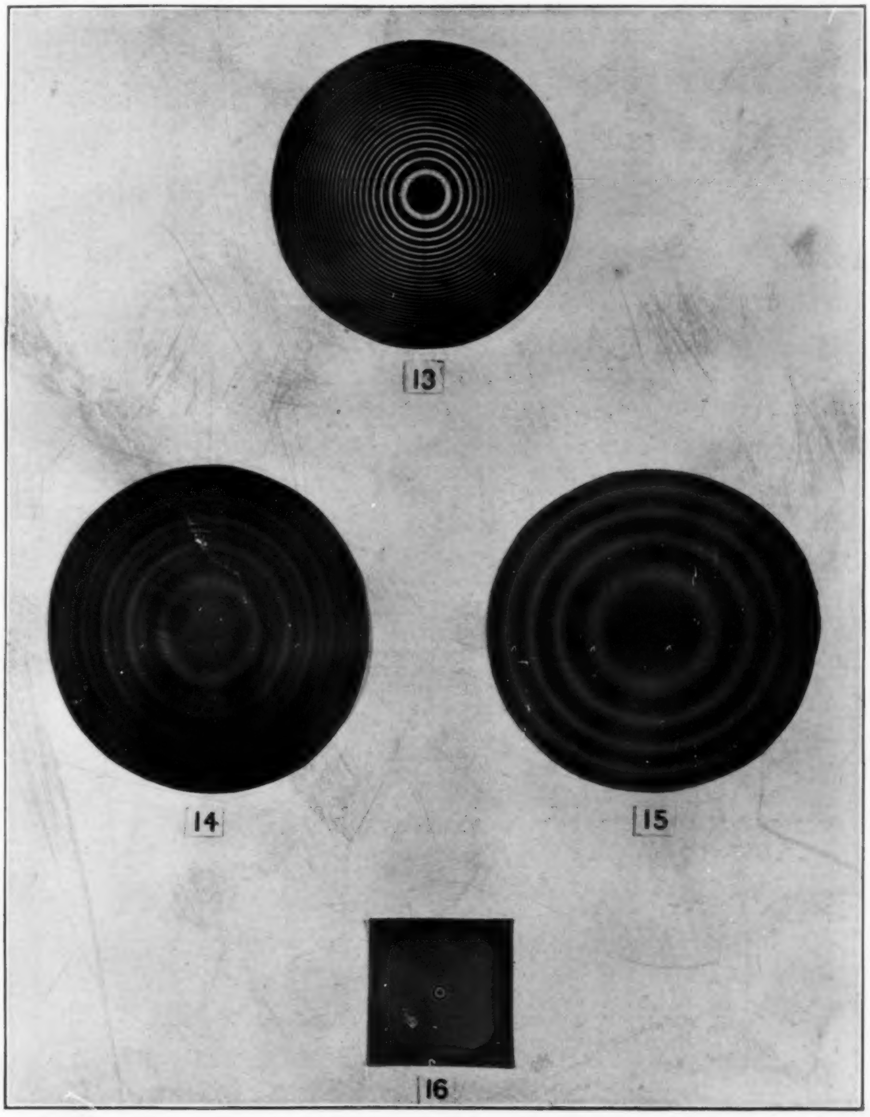
IV. RADIAL VELOCITIES OF TWENTY STARS HAVING SPECTRA OF THE *ORION* TYPE. *By Edwin Brant Frost and Walter Sydney Adams.*

V. THE SPECTRA OF STARS OF SECCHI'S FOURTH TYPE. *By George Ellery Hale, Ferdinand Ellerman, and John Adelbert Parkhurst.*

VI. ASTRONOMICAL PHOTOGRAPHY WITH THE FORTY-INCH REFRACTOR AND THE TWO-FOOT REFLECTOR OF THE YERKES OBSERVATORY. *By George Willis Ritchey.*

VII. THE ORBIT OF THE MINOR PLANET (334). *By Kurt Laves.*

PLATE XX.



INTERFERENCE FRINGES.

FIGS. 13 and 16, green mercury line.
FIGS. 14 and 15, sodium lines.